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The Feasibility of Fiber Optic Communications for Emerging Rail Traffic Management Systems

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The Feasibility of Fibre Optic Communications for the Highway 401 Traffic Management System

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Ottawa, Ontario

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Research and Development Branch, MTC

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1.0 EXECUTIVE SUMMARY

Introduction

The Ontario Ministry of Transportation and Communications (MTC) proposed a design for a traffic surveillance and control system in the Highway 401 Corridor Traffic Systems Management Study completed in 1980. The broadband communications system for video and data was based on coaxial cable technology, the cost of which represented approximately half of the total estimated cost of the system. The study also identified fiber optic technology as a possible alternative, and MTC later commissioned Andrew T. Schindler & Associates Inc. (ATS) to carry out a feasibility study. The study was carried out under the general direction of Messrs. E. Ryerson Case, Program Manager, Systems Research Branch, J. Tsai, Project Research Engineer, and Lamberto F. Gomes of the Communications Division, MTC.

The purpose of the feasibility study was to develop a system configuration using fiber and/or hybrid technology, assess the available technology and determine the practical limitations, generate cost models and make comparisons with

the cost of a coaxial system, and develop an implementation plan.

Methodology

In the methodology used by the ATS Team in this project, the communication service requirements were first formulated and an implementation plan for the program was developed with MTC. The communications environment within which the system would operate, was defined and the communications transmission standards specifying the quality, were developed. In order to meet these general requirements, seven system configurations were designed using the data base maintained by ATS. We also quantified the system hardware requirements for Stage I.

In order to obtain an up-to-date perspective on the available technology and costs, as well as to identify this potential opportunity to suppliers, the above information was provided to some thiry major international firms. We received responses from approximately 80 per cent of these, although many were hard-pressed to provide information because of the high and growing demand for information

of this type. We also attended an International Exposition on Fiber Optics Communications in which additional firms were acquainted with the MTC requirements and further information was obtained.

Armed with all this information, we proceeded to develop detailed configurations for four video systems, two data systems and the necessary support systems (such as voice and power). The major considerations in configuring the various systems were (a) reliability, (b) quality of service, (c) minimal complexity of operations and (d) easy extension to Stage II. This necessitated the creation of unique system designs for this type of application since none were readily available.

Background on Fiber Technology

Optical fibers were introduced into the telecommunications field in 1975 and since then the number of applications has grown very rapidly. In Canada alone it is estimated that there are some 25 separate installations. The advantages of fiber technology include:

(a) very low signal attenuation (loss);

(b) immunity to interference from power lines, radio transmitters, cars, etc.;

(c) increased reliability;

(d) stable transmission quality;

(e) requires simple and reliable terminals;

(f) potential capability for increasing distance coverage or new services by multiplexing;

(g) small, strong and easy to install;

(h) expected life of 30 years or more.

Results

Given the above general fiber characteristics, we examined a system layout for installation on one side as well as for both sides of the highway. Because of their increased reliability, fiber optics systems are suitable for installation on one side of the highway, which results in simplified maintenance (fewer locations and more concentration of equipment) and lower installation costs. Installation on both sides of the highway was examined in order to provide a direct cost comparison with the coaxial cable system.

Altogether, 16 different configurations were designed and

costed. The main results together with the cost of the coaxial cable system derived from the MTC study, are shown on a per metre of highway basis in the following table:

Estimated Total Cost for Selected Options

Option	Both Sides of the Highway	One Side of the Highway
Coaxial Cable	$77.01	-
Fiber Systems		
Baseband	$62.84	$51.10
Switched Baseband	$52.75	$43.03
FM Multiplex	$54.64	$43.35
Digital	$63.63	$52.73

These costs include the cost of a data system on fiber, an on-line power system, a voice system, line support structure and all installation costs.

All of the fiber systems can easily be extended to provide service to Stage II of the project. The digital system has a limitation in that from a given zone with three cameras, only one camera can be used at a time.

The reliability of any of the systems is determined mainly by the quantity of its electronic subsystems. On this basis, the baseband system is the most reliable. The switched baseband and F.M. multiplex systems are also highly reliable, and more reliable than the digital system.

Conclusions and Recommendations

On the basis of technical and cost considerations, the switched baseband and the F.M. multiplex systems appear to be good alternatives to the coaxial cable system. The total costs of each of these systems for the 26km of highway, Stage I system are:

1.	Coaxial cable - both sides of highway (1979 MTC estimates);	$2.0 million
2.	Switched baseband - one side of highway;	$1.1 million
3.	F.M. multiplex - one side of highway.	$1.1 million

Thus, the two fiber systems will cost 45 per cent less than the coaxial cable system.

We, therefore, recommend that one of these two fiber systems be chosen for the program. It is recommended that a fiber

cable system with a separate copper cable be installed on one side of the highway with cross-overs at intersections.

Both the F.M. multiplex and baseband switched systems use subsystems that are readily available from the suppliers identified in the report, although slight modifications may be necessary to fit this particular application. On the basis of the available information, it is difficult to choose between the two systems. We, therefore, recommend that an experimental simulation should be undertaken to determine their precise technical limitations, and to establish the signal level boundaries for the final system design. The simulation experiment will, moreover, provide a basis for verifying that the systems are optimal for this unique application.

2.0 INTRODUCTION

The purpose of this report is to present the results of a feasibility study on fiber optic technology as a possible alternative to a coaxial cable system for use in a traffic surveillance and control system in the Highway 401 Corridor. Part I of the report provides the initial definition of system requirements, program, standards and configurations together with a copy of a letter sent to some thirty international suppliers. Part II provides a detailed analysis of systems, costs and implementation plan.

PART I: INITIAL DEFINITION OF SYSTEM REQUIREMENTS, PROGRAM, STANDARDS AND CONFIGURATIONS

ANDREW T. SCHINDLER & ASSOCIATES INC.
15 Amberwood Crescent
Ottawa K2E 7B7
Canada Tel. (613) 225-1432

Dear Sir:

We have been appointed by the Minister of Transportation and Communications of Ontario (MTC) to carry out a feasibility study on Fiber Optic Transmission System for the Highway 401 Corridor Network in Toronto, Ontario. We believe that your company has an interest and strong capabilities in this field and we would like to request a budgetary quotation and technical information from you on all or parts of the proposed Fiber Optic Transmission Systems.

The attached background report outlines the proposed MTC implementation plans, service requirements and provides some possible system configurations, design criteria and estimated quantified subsystem requirements.

We would be pleased to receive from you a budgetary quotation for the complete system based on the configurations attached or other configurations that you may want to propose. Also we would like to have a unit cost breakdown of the major components in the event that a combination of suppliers equipment will provide a better or more economic system solution for this application.

Your quotation should include:

a) An estimate of a complete system in one or more configurations;

b) List of spare parts for system and unit costs;

c) List of major components subsystems and unit costs;

d) Schedule of availability;

e) Technical characteristics of components, subsystems and the system.

.....2

In order to comply with the overall schedule for this project, we will require your reply by 3rd August, 1981. In the event that the Canadian postal strike continues, please use courier service.

We would appreciate your cooperation in this matter. If you should have any questions regarding this request, please let us know as we would be pleased to visit your plant to discuss this project with you in order to clarify any of the project requirements.

Yours truly,

ANDREW T. SCHINDLER & ASSOCIATES INC.

A. T. Schindler,
President.

ATS/ds
Encls.

3.0 GENERAL BACKGROUND

Based on the experience gained from the Queen Elizabeth Way Freeway Surveillance and Control System project which became operational in 1975 and studies pertaining to Highway 401, MTC is planning to implement on a staged basis a traffic management system for the Highway 401 corridor. The purpose of the system is to increase Highway 401 traffic flow with improved safety by utilizing most effective technology. This is accomplished by:

1. Traffic surveillance information and monitoring of traffic flow;
2. Incident management: identifying and clearing obstacles on the Highway in an efficient manner;
3. Motorist information system: rerouting traffic on the Highway 401;
4. Future provisioning of entrance ramp metering: limiting access on to Highway 401.

This is achieved by an automatic system with a manual override consisting of the following major

sub-system components:

1. Central Traffic Control Computer;
2. Traffic Control Centre;
3. Data Communications Subsystem;
4. Broadband Cable Communication Network;
5. Vehicle Detection Subsystem;
6. Closed Circuit Television (CCTV) sub-system;
7. Changeable Message Sign (CMS);
8. Ramp Metering Subsystem;
9. Communication Interface with Adjacent Traffic Control System.

The purpose of the ATS/MTC project is to determine the technical feasibility and economic viability of using fiber optic technology for this application in the interconnection of subsystems 1, 2, 3, 4, 6 and 9 as identified above. In order to do this, it is imperative that the functional, physical and environment characteristics are understood clearly in order to optimize the network configurations in a way as to provide a fiber-based communications system which has the flexibility, reliability and transmission

quality which is cost effective and performs in an acceptable manner for immediate and future MTC needs.

4.0 MTC IMPLEMENTATION PLAN

In considering fiber optic technology for this application, it is important to know the implementation plan so that an optimum network configuration can be developed that not only meets the first stage requirements but also provides for future planned system growth in terms of services and coverage.

The system configurations that will be developed during the next phase of this project will be to take full advantage of technological developments which are taking place now and significant cost reductions will be realized in the future as the demand for fiber optic system continues its rapid growth.

The MTC network development plan of the Traffic Management System consists of three major stages. The first stage has been approved by the Ontario Government. The three stages are the following:

Stage I

Planned Start:	1983
Planned Completion:	1985
Highway 401 Section:	Hwy 427 to Hwy 404
System Length:	26 km.
No. of Interchanges:	12
No. of Video Cameras	23
No. of Changeable Message Signs:	19
No. of Traffic Detection Stations:	70

Traffic Control Centre located mid-way (North of 401 in the MTC complex).

- OPP control centre located on South Side of 401 opposite MTC complex.
- Cable to be concealed.

  80% of length suitable for burial

  20% of length suitable for conduit.

- Number of Data Modems: (Estimated) 183

Stage II (Extension of Stage 1)

Planned Start:	1985
Planned Completion:	1987

Highway Sections:

	Estimated System Length
- East to Kingston Road:	16km
- West to Mississauga Road:	16km
Total System Length:	32km

Major System Elements:

- No. of Traffic Detection Stations:	150
- No. of Changeable Message Stations:	29
- No. of Video Cameras:	42

Stage III

Planned Start:	1987
Planned Completion:	1990

Highway Section:

	Estimated System Length
- 427, 409 and QEW:	19km
- Proposed 403:	20km
- Gardiner Expressway & Don Valley Parkway*	26km
Total System Length:	65km

* Possible future interconnections.

5.0 STAGE 1 COMMUNICATIONS REQUIREMENTS

The communications requirements for Stage 1 consists of the following:

1. Video;
2. Data;
3. Voice.

5.1 Video

The visual surveillance of the 12 lane highway will be accomplished through placement of some 23 cameras which will be spaced 1.6 km. apart with additional cameras at the major 12 interchanges. The cameras will be mounted on 50 foot stressed concrete poles to minimize pole whip in high winds. These cameras will be remotely controlled from the traffic control centre. The remote controls will provide for the following camera functions: pan, tilt, zoom, focus, iris control and windshield wiper actuation. The cameras chosen for this application will be used

for daytime and nightime operation. They will be enclosed in a weather-proof housing that has air filters and exhaust fans.

The closed circuit camera specifications are the following:

1. Signal to Noise....44dB @ 12 MHz band-width;
2. Band-width....12 MHz automatically adjusted to as low as 2 MHz to optimize signal to noise ratio at lowest light levels;
3. Video Output....1.1V composite, adjustable two isolated outputs at 75 ohms;
4. Sync....EIA RS-170 broadcast standard;
5. External Controls....Beam focus, light control, AGC ON/OFF control, power ON/OFF;
6. Power....20 watts nominal, 120V, 50-60 Hz;
7. Video and Drive Connectors....BNC;
8. Environment....plus 5 degrees F. to 140 degrees F., 0 to 95% R.H.

At the bottom of every camera pole a cabinet will be provided with environmental control (heater and fan).

5.2 Data

There are three main functional categories of data communications in this system and these are the following:

1) Detector Station data retrieval;
2) Changeable Message Sign Control;
3) Ramp Control (provisional).

The detector stations will be placed along the highway at numerous locations and will monitor vehicle traffic flow which will be aggregated by a local controller and local data will be transmitted to a master computer at the traffic control centre. The characteristics of the data signalling are that up to 100 bytes of data are transmitted from each of the polled terminals at 15 second intervals. Stage I will require an estimated 70 detector stations.

The changeable message signs (CMS) will be provided to instruct motorists on traffic

conditions ahead and alternate traffic routing. Some 19 CMS's will be required for Stage I and up to 100 bytes data message length per direction, 1 message every 30 seconds.

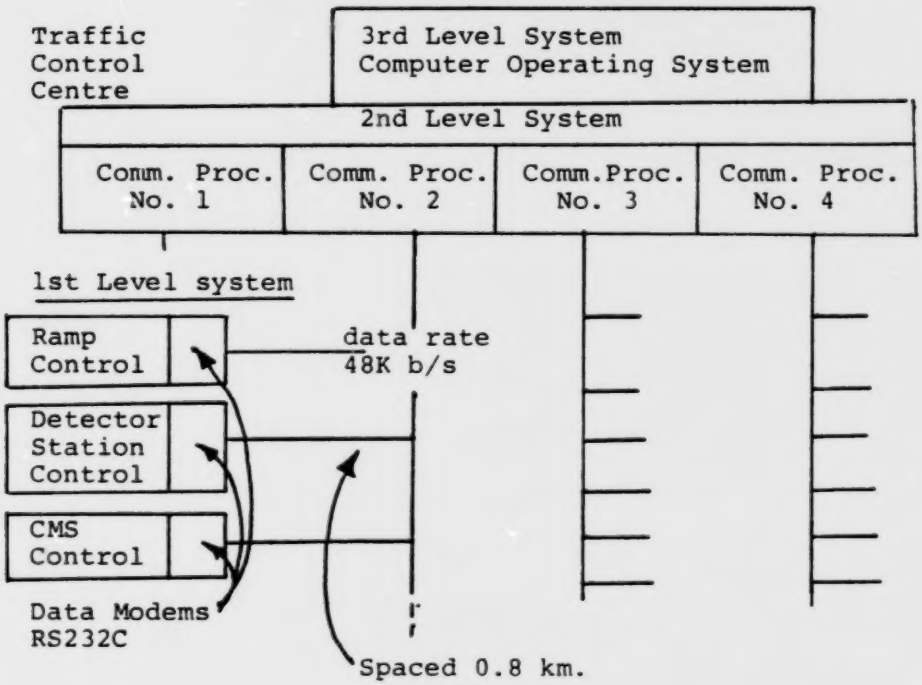
The ramp control will be provided by inputs from main line detectors and ramp detectors which will be aggregated and analysed by a ramp controller located at the ramp and will provide instructions to metering signal lights at the ramp and also via a data modem to the traffic control centre. The estimated data message length per direction is up to 100 bytes at a frequency of one message every 30 seconds. Stage I will require some 71 ramp metering stations that will be connected to the data network.

In addition, there is a network requirement to connect the traffic control centre with the Metro Toronto Traffic Control Centre where it is estimated that 1,000 bytes of data message length will be transmitted, 1 message per minute.

The proposed configuration of the network is a 3 level distributed hierarchial structure data processing system, consisting of field micro-processor, traffic control centre micro-processor and a mini computer. The first-level system, is discussed above. Interacts with a second level is where the most significant communications requirements exist. The second level system consists of the following communications processors and the associated data modems:

1. Communications Processor No. 1 to handle east bound traffic located east of traffic control centre;
2. Communications Processor No. 2 to handle east bound traffic located west of traffic control centre;
3. Communications Processor No. 3 to handle west bound traffic located west of traffic control centre;
4. Communications Processor No. 4 to handle west bound traffic located east of traffic control centre.

Data Network Configuration:



The distributed network architecture has been chosen by MTC to increase overall system reliability.

It is not essential that data be transmitted on the fiber for Stage 1 application. However, adequate fiber capacity must be provided for possible future new MTC data service requirements.

5.3 Voice

The prime requirement for voice service is for maintenance purposes, and access to an order wire. Quality audio must be provided at all locations where maintenance access is required, e.g. cameras, changeable messages, data modems, etc.

The secondary requirement for audio is for emergency highway telephone communications. Up to 24 locations in Stage 1 may be required. This is a service option only at this time and it is a non-essential system feature.

6.0 ENVIRONMENT - CONSTRUCTION AND OPERATION

In order to provide secure and reliable transmission on all communication facilities, it is important that all components of the network be designed, constructed and maintained to meet established transmission and reliability standards.

The network should be designed to provide continuous availibility of audio, video and data services that are not degraded by external environmental conditions. This means that all cable, equipment and apparatus through design and installation must withstand all environmental hazards along the highway 401 corridor with a minimum degradation to service.

The cables must be protected by burying or enclosed in ducts to protect them from physical damage. All components must be designed, housed and protected to withstand the climaticconditions, temperature variation, electrical interference, vibration, corrosion and other external factors to maintain the specified standard of service for the life of the system.

The general configuration of this communication network proposed would consist of a composite optical fiber and copper cable placed underground embedded in the shoulder of the Highway 401. The major part of this cable, approximately 80%, could be buried directly in the overburden at a depth of 24 inches to 30 inches. The sections at the overpass and intersections would be placed in conduits. Most of the electrical conduits are already in place, and terminates in apparatus and cross connections enclosures located at each intersections. These enclosures are to be properly environmentally controlled and physically located to be secure and easily accessable for installation operation and maintainance.

This configuration would permit placing all feeder cable along and distribution cable traversing the highway in one operation. These cables would be tested and then terminated in the apparatus and cross connection terminals.

The installation of the electronics such as amplifiers, detectors, cameras, signs and other equipment would

follow and be placed in the environmentally controlled apparatus and cross connection enclosures.

This installation would avoid cable splices in the feeder cable and permit all repeaters and amplifiers to be located in the environmentally controlled enclosures. All cables entering the enclosures and ducts will be sealed to prevent the entrance of moisture, but permit sufficient movement to compensate for temperature variations.

The enclosures should be so located to permit easy, safe access to allow for installation and maintenance as the major part of the installation will be performed here and maintenance as required for the life of the system.

The cable installation would be the most permanent part of this installation with a 20 year life and consideration should be given to ensure that pairs are provided initially to permit extension of this network. The electronics and other equipment have a shorter life, from 2 to 15 years, but can be easily tested and replaced when required on a normal maintenance cycle.

7.0 COMMUNICATIONS TRANSMISSION STANDARDS

As identified in the previous report, this system requires the transmission of 3 basic types of information: voice, data and video. To ensure that these types of information are economically and reliably transmitted, overall communications transmission standards are required for each. The system must be capable of meeting these requirements for the initial installation (stage I) and must be up-gradable to also meet these requirements when the system is extended (Stage II). Hence, suppliers will be required to show how their system can be upgraded to meet these requirements for Stage II.

7.1 Voice

The voice component of the communications requirements for this system is essentially an order wire type service linking the remote equipment locations and the traffic control centre. Emergency road

side telephones could also be required, either on this order wire, or on a separate party line circuit. Transmission requirements, therefore, are similar to those for standard telephony. Basic requirements are:

Band-width	-	200 Hz to 3.2kHz
Noise	-	30 dBrnc
Electrical Loss at 1Khz	-	8dB

7.2 Data

The data component of the communications requirements for this system will carry data for vehicle detection, data to and from the ramp controller, data to and from the Changable Message Signs, and data to and from the video camera controllers. This data will be carried on an asynchronous duplex base structure, sequentially polled for the traffic control centre operating at 56kb/s. The error performance of this data bus shall be better than 1 bit error per 10^7 bits transmitted.

7.3 Video

The video component of the communications require-

ments for this system will carry the signal from each video camera to the traffic control centre, i.e. star configuration. Quality of transmission required shall be similar to CATV service. Basic requirements are:

Signal-to-noise Ratio - 40dB

Signal Frequency Interference - 57dB

Differential Gain ± 2dB*

Differential Phase ± 5°*

Cross Modulation - 48dB

* Differential phase and gain requirements are fundamental for colour transmission. Since this system is black and white, these requirements may be relaxed.

7.4 Additional Requirements/Guidelines

In addition to the above requirements, the system shall exploit the advantages of fibre technology. The system shall:

1. Span large distances with minimum repeaters. This impacts cost, reliability/ and maintainability;
2. Provide a stable loss and frequency

response to minimize operation costs;

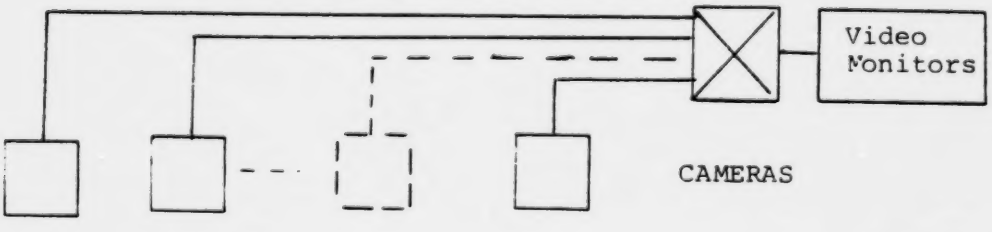
3. Be immune to interference from power lines, radio and television transmitters, and other sources of RFI;
4. Be capable of being extended in length by cascading additional line sections (Stage I & II). This cascading shall not require any addition to condition of the stage I line;
5. Allow future multiplexing of several channels/fiber (Stage II);
6. Require only simple, reliable terminals;
7. Require a minimum of development to implement;
8. Benefit from future evolution of technology.

7.5 Reference Circuits

The basic system configurations assumed are the following:

Video

Star configurations; camera output



8.0 ALTERNATE SYSTEM CONFIGURATIONS

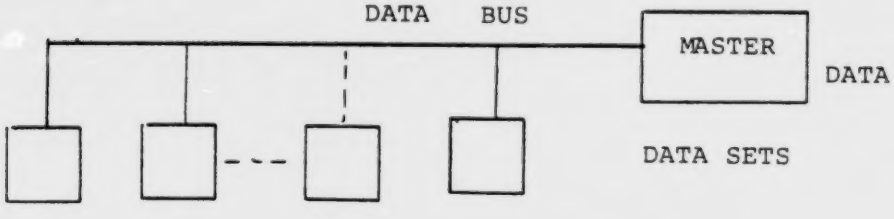
The fiber optics systems technology is developing at an ever-increasing pace as the markets develop for this unique technology. The system configurations developed for this application vary in complexity and maturity of opto-electronic devices. Hence, the cost of the devices is expected to be drastically reduced during the time frames of the staged system introduction. The seven system configurations developed illustrate various possible modulation techniques. A system could use any one of these modulation schemes, or combination to form hybrid configurations.

8.1 Baseband

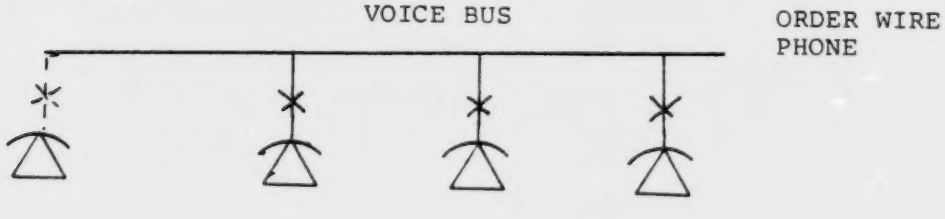
The baseband video signal is used to modulate the intensity of the light source. The modulated light signal is transmitted through the fiber optic cable to an optical receiver which detects the variation in light intensity to recreate the video signal.

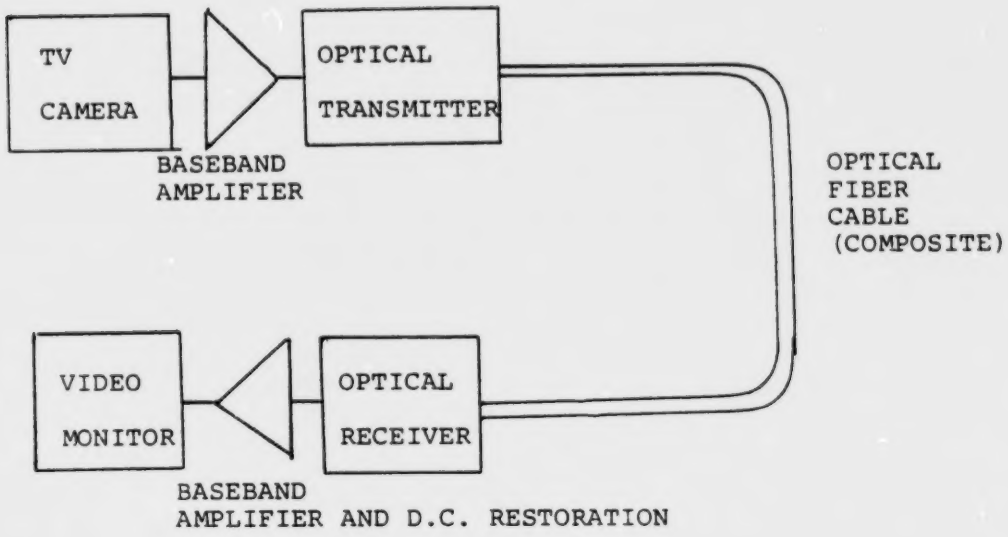
Data

CMS orders and data, detector station data, ramp control data/orders video camera controls(?) (or separate pair for camera controls)



Voice





Characteristics

1. Transmission Method:

   - baseband; 0 - 4.2MHz

2. Light Source:

   - type LED or Laser

3. Fiber:

   - graded index
   - 1 fiber/TV channel
   - required characteristics:

     Attenuation - 4dB/km

     Dispersion - 600MHz/km

4. Photo-diode

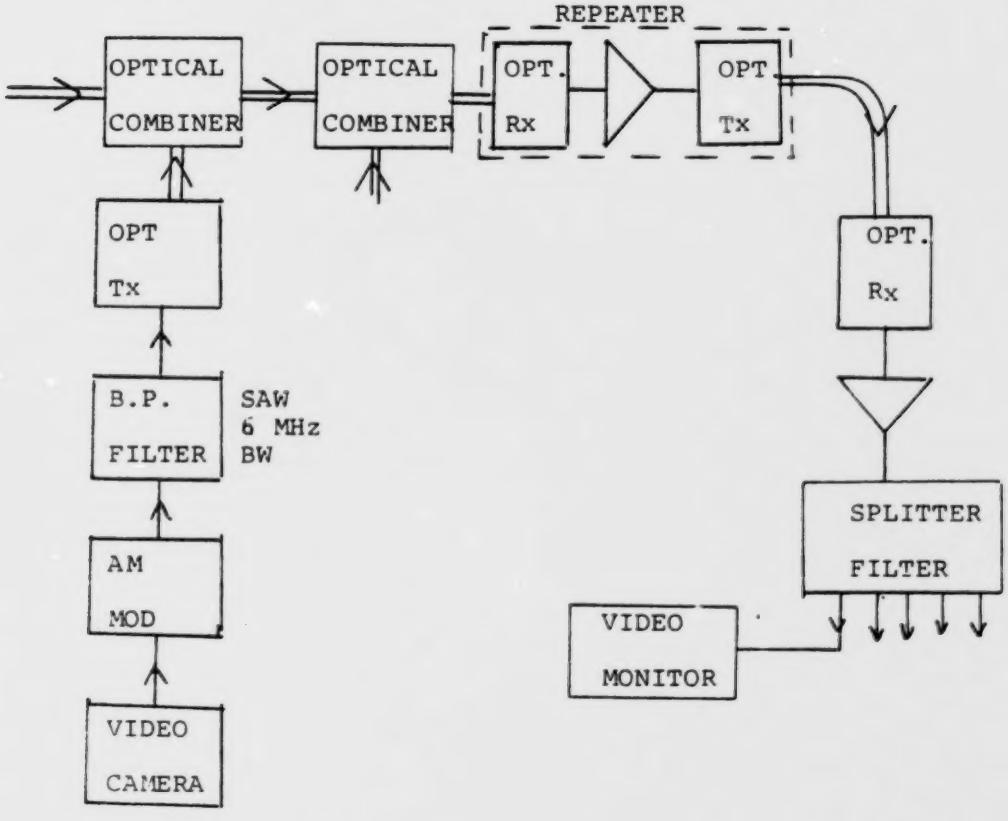
   - PIN or APD type

5. Baseband Amplifier

   - 0 - 4.2MHz

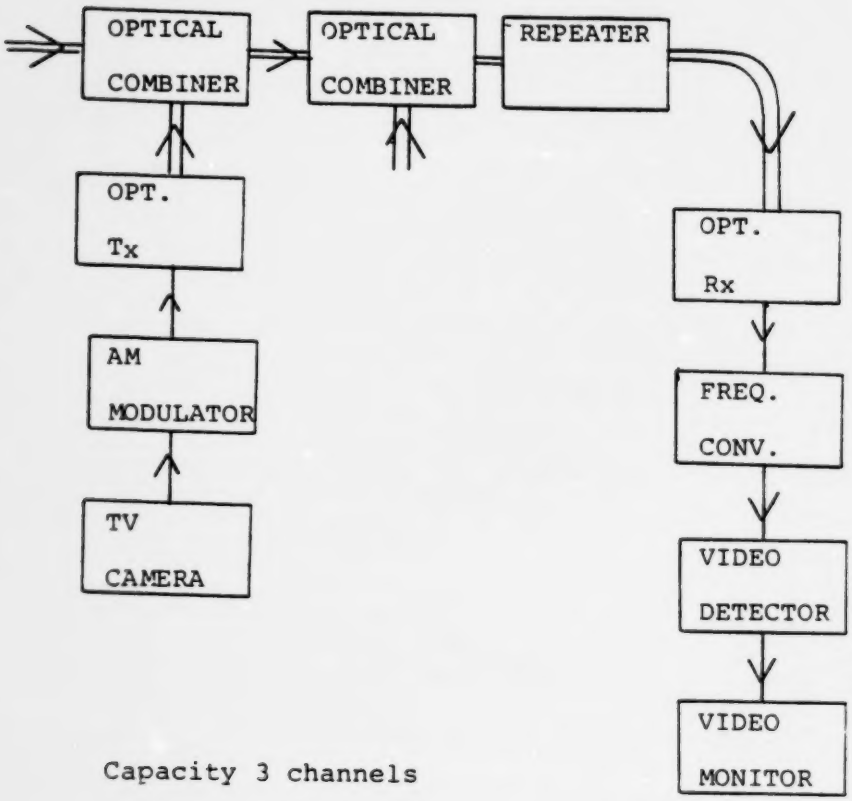
8.2 VSB AM Multiple Channels

Vestigial Sideband Amplitude Modulation system is standard broadcast mode signal. Up to 3 video signals can be modulated each at a different frequency and coupled on to a single optical fiber. The composite signal is detected by the light source and frequencies are separated by filtering. Repeaters are required every 8km approximately.



8.3 Double Side Band AM

This system requires more bandwidth than V.S.B. AM but principle of operation is similar.

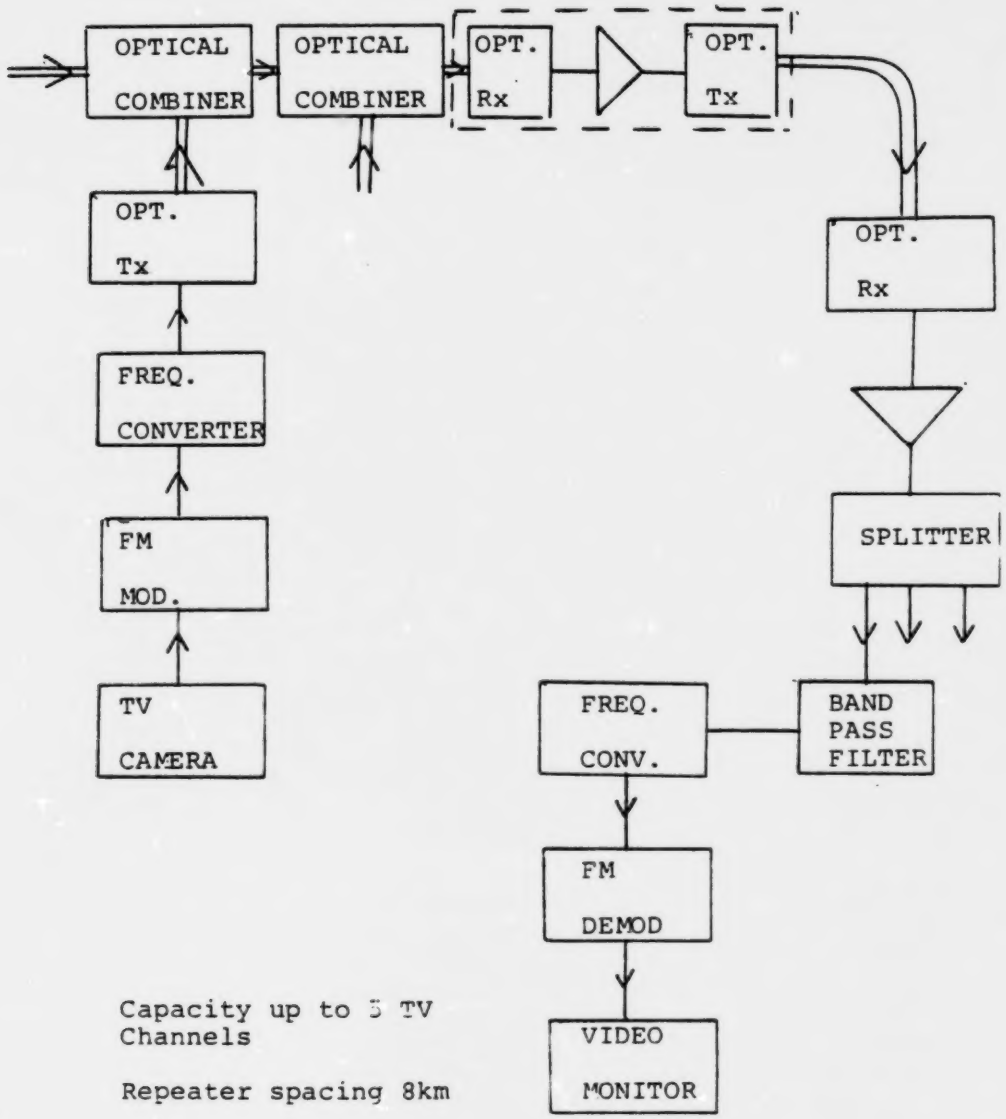


Capacity 3 channels

Repeater Spacing 6km

8.4 Multichannel FM

Frequency modulation technique provides approximately 10dB S/N advantage over AM systems.

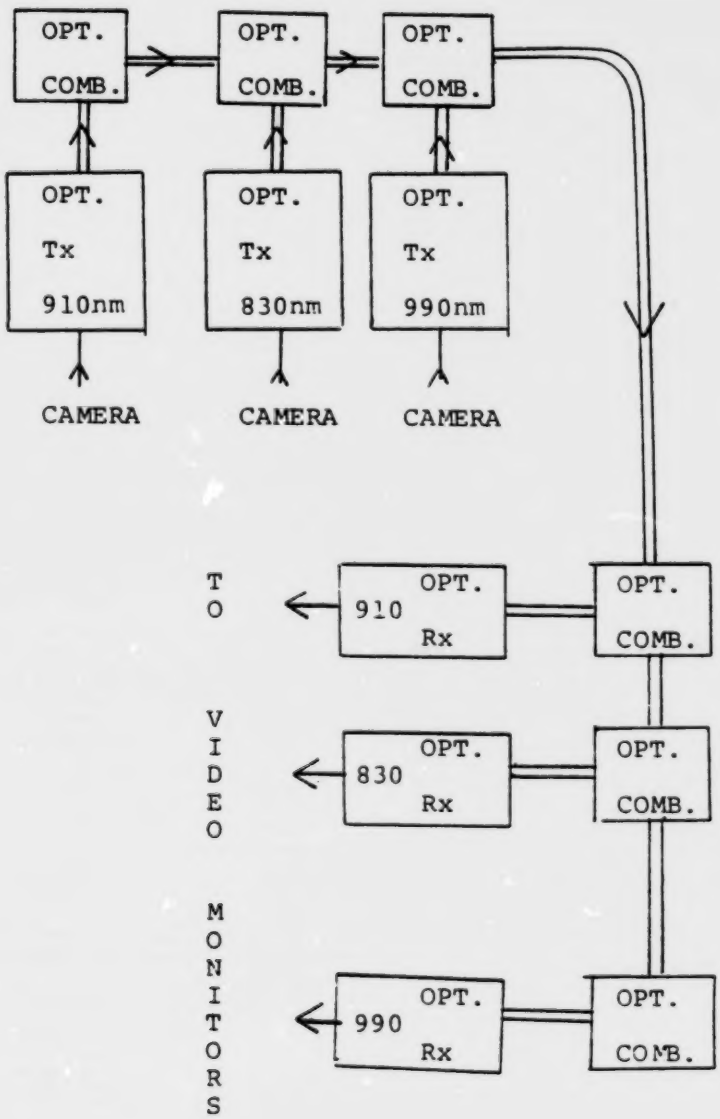


Capacity up to 5 TV Channels

Repeater spacing 8km

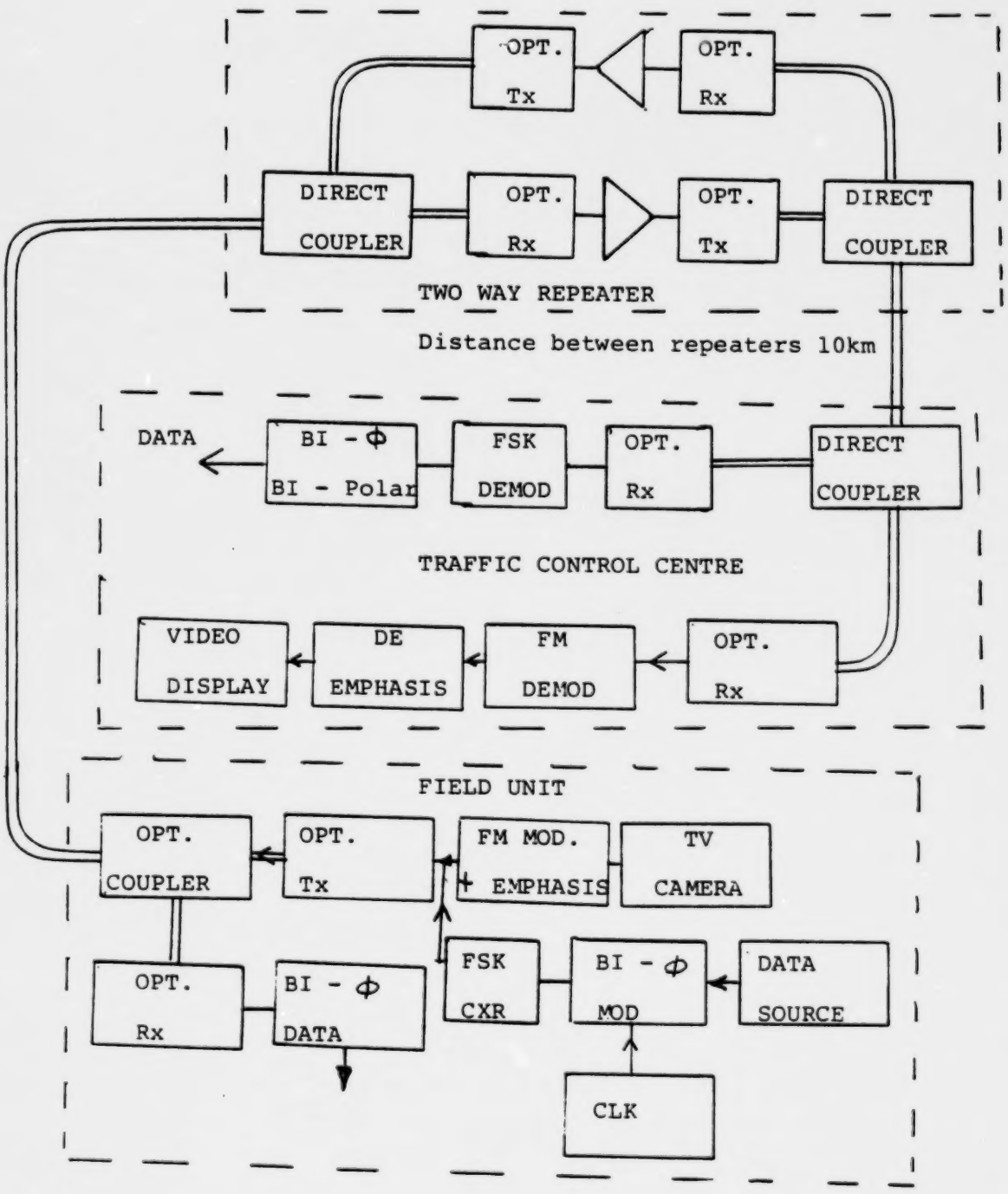
8.5 Wavelength Multiplexing

The principle of operation of this system is the use of different light frequencies.

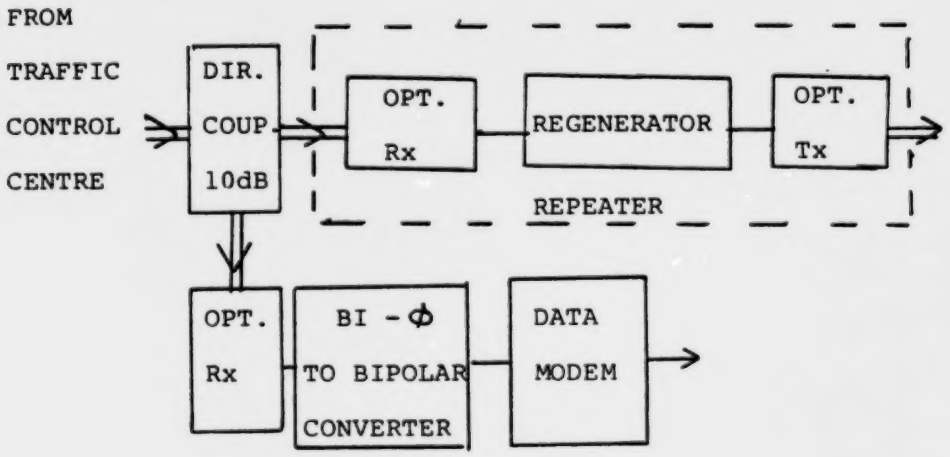


This technique may be used in combination with techniques outlined in 1, 2, 3, and 4.

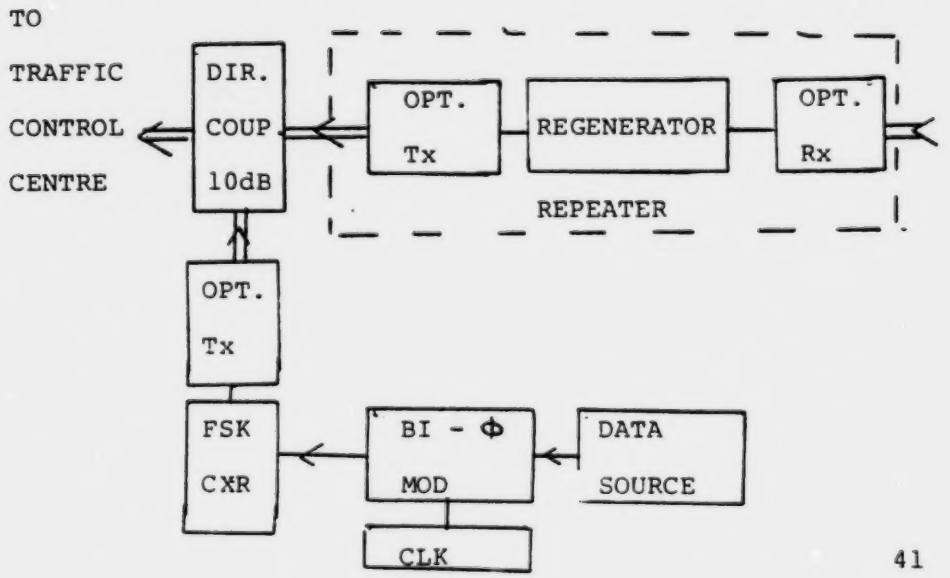
8.6 FM Single Channel Video with Data Two Way System



8.7 Single Fiber for Data T.D.M



Distance between repeaters 10km approx.



9.0 ESTIMATED QUANTITIES OF SYSTEM HARDWARE REQUIREMENTS FOR STAGE I

Given the system needs and requirements the following are gross estimates of fiber composite cable and subsystem quantity requirements for Stage I:

9.1 Estimated Fiber Requirements*- Stage I

System Type	Fiber-Km Minimum	Fiber Cable Sheath Km	No. Fiber/Sheath
1. Baseband Video	312	52	6
2. VSB AM	104	52	2
3. Double Side band AM	104	52	2
4. Multichannel FM	52	52	1
5. Wavelength Multiplexing	104	52	2
6. Single Channel FM & Data	312	52	6
7. Single Fiber for data TDM	52	52	1

* Estimates do not include the following margins which should be added to by suppliers:

1. Approximately 10% should be added for drop cable to connect camera;
2. Additional fibers should be provided for spares in case of damage during installation or operations;
3. It is assumed that there are cables placed on each side of Highway 401;
4. Provision should be made for Stage II expansion;
5. It is assumed that up to a maximum of 6 cameras will be connected to each cable on each side of the highway and each side of traffic control centre;
6. The fiber composite cable should contain a minimum 4 pairs of 19 ga. copper for possible data transmission and order wire;
7. The distance between cameras is 3.2km on one side of highway;
8. In addition to providing information on fiber cables, please provide additional information on couplers, splices and terminations of fibers.

9.2 Estimated Major Transmission Subsystem Requirements*

Stage I

System Type	Repeaters	Optical Couplers or Combiners	Optical Transmitters & Elect. Modulators	Optical Receiver & Elect. Modulato
1. Baseband Video	?	0	23	23
2. VSB AM	4	23	23	23
3. Double Side Band AM	4	23	23	23
4. Multichannel FM	4	23	23	23
5. Wavelength Multiplex	4 ?	23	23	23
6. FM Single Channel Video & Data	8	23	23	23
7. Single Fiber for Data T.D.M.	23	23	23	23

*1. Suppliers should recommend adequate spare parts subsystems for maintenance facilities;

2. Suppliers should provide technical characteristics of the listed subsystems and additional components;

3. Suppliers should provide estimates of MTBF for subsystems;

4. Suppliers should provide all cost information;

5. Suppliers should provide information on expansion of the system from Stage I to Stage II;
6. Any Hybrid systems proposals or other system designs provided by suppliers will be considered on an equal basis during the evaluation of systems.

For the first stage, it is most likely that a composite cable containing baseband video on fiber (1 video signal per fiber) together with voice and data on copper pairs will be the most suitable system for the following reasons:

1. Very high reliability;
2. High transmission quality;
3. Flexibility for future expansion to Stage II and III;
4. Equipment availability (off the shelf).

The potential for future growth both for Stage II and other services could be easily satisfied.

PART II: DETAILED ANALYSIS OF SYSTEMS, COSTS AND IMPLEMENTATION

10.0 Survey of Suppliers

Some twenty-one suppliers of systems and subsystems have been approached with a comprehensive outline of the alternative system configurations, transmission standards, and MTC implementation plans. ATS requested that the suppliers respond with information regarding sub-system technical specifications, price information, etc.

The following is a list of Canadian firms that have been included in the survey:

1. Canstar Communications Ltd., Scarborough, Ont.
2. Northern Telecom Canada Ltd., Saskatoon, Sask.
3. Foundation Electronic Instruments Inc., Ottawa, Ont.
4. Interdiscom Systems Limited, Winnipeg, Man.
5. Digital Communications Ltd., Mississauga, Ont.
6. Phillips Cables, Brockville, Ont.
7. AEL Microtel, Burnaby, B.C.
8. Gandalf Communications Ltd., Ottawa, Ont.
9. Fairnon Canada Limited, Dorval, Que.
10. Nippon Electric Co. Ltd., Toronto, Ont.

In addition, eleven American companies were approached for information regarding this application. They include the following:

1. Times Fiber Communications, Connecticut.
2. Harris Corporation, Florida.
3. I. T. & T., Virginia.
4. Valtec Corp., Mass.
5. Corning Glass Works, New York.
6. Varo Inc. Texas.
7. Union Carbide Corp., California.
8. RCA Corp., Penn.
9. CATEL, California.
10. Siecor Optical Cables Inc., New York.
11. Laser Diode Corp., California.

All of the Canadian companies with the exception of Northern Telecom indicated an interest in the project and responded in meetings, telephone calls or in writing. American firms also responded to the ATS request for information. Some responses were more comprehensive than others.

It should be noted that the fiber industry is booming at present and suppliers are swamped with requests for information on costs, specifications and supply. In our case it was more difficult to obtain information since the planned starting date of the project is 1983.

In addition, we attended the International Fiber Optics and Communications Exposition at which we approached twelve additional suppliers to obtain up to date information and to make them aware of the MTC potential requirement.

The graded index-type fiber required for video systems in this application has become one of the standards in the industry. The leading manufacturer of fiber in North America is Corning Glass in New York and they are the main source of fiber to the fiber cable manufacturers. There have been installations of fiber cable for different systems and as a consequence there has been a great deal of field experience with it. The two-window fiber which will permit a very economical extension to Stage II of the program using longer wavelengths on the fiber already installed in Stage I, is now available from a number of alternate suppliers.

The developments in the technology of lasers have also led to signficant improvements on both their performance and life expectancy, making them much more reliable.

A number of suppliers at the International Exposition were displaying long wave electro-optic subsystems which included multiplexes, a variety of combiners (couplers) and optical switches, that are now available. We also held discussions during the Exposition with many people who have been installing fiber systems, and the practice of providing spare fibers in case of breakage during installation is being done away with because of improvements in the strength and the good experience gained from numerous installations. Another important trend is that the fiber cable design which has in the past had a tendency of over-protection from the physical environment, is being greatly simplified making the cable more flexible, lighter and simpler to install.

It also seems to us from discussions we held with many suppliers that the budgeting estimates for fiber cables provided to us by suppliers, are subject to a reduction of about 10 - 20 per cent through negotiation. In addition, since the introduction of fiber cable in 1975, there has been a downward trend in the price of the cable and this is likely to continue over the next few years. For example, in 1977, a single fiber cable cost $3 (U.S.) per metre and at present the cost is less than half of this.

During the course of the project, we identified the suppliers of material needed for video and data systems, and of fiber cable. These are listed below for the different types of material. It should be noted that the suppliers listed for the different types of equipment or cable, have particular strengths and weaknesses which should be considered before orders are placed.

Suppliers of Digital Systems for Video (90 Mb/s rate)

- International Telephone & Telegraph
- Digital Telecommunications Limited
- Nippon Electric
- Farinon Harris Corp.

Suppliers of Subsystems for Video Baseband and FM

- Foundation Instruments Limited
- Hitachi (all optical and electronic subsystems)
- AEL Microtel
- Koptron Inc. (directional couplers, optical switches)
- Hewlett Packard (baseband switches)
- Catel Inc.
- Nippon Electric (couplers, switches, opts-electronics)
- Interdiscom Systems Limited (system electronics)
- Motorola Semiconductor
- Fujitsu Ltd.

Supplier of Fiber Cable

- Phillips Cables
- Canstar Communications Ltd.
- Siecor Optical Cables Inc.
- Times Fiber Communications
- Valtec Corporation
- I. T. & T.

Suppliers of Data Systems

- Digital Telecommunications Limited
- Gandalf
- Lynch Systems Inc.
- Interdiscom Systems Limited
- Nippon Electric Ltd.
- Hitachi
- Fujitsu

11.0 VIDEO SYSTEMS INSTALLED ON ONE SIDE OF HIGHWAY

11.1 Baseband System/One Fiber per Camera

11.1.1 Description:

The baseband system is a basic design consisting of a dedicated single fiber for the transmission of signals from each camera. The signal generated at the camera is fed through an amplifier to a laser which in this application has to be temperature-stabilized in the range 0 - 40 degrees Celsius. The bandwidth required for maintaining a signal/noise ratio of 40 db or better is 6 MHz. The typical laser emission power is plus 5 dBm and the sensitivity of the receiver located in the control centre is approximately minus 32 dBm, resulting in an attenuation limitation of 37 dBm over the limit. Given these transmission limitations, we recommend that a repeater be used every 6.5km to maintain the transmission objectives stated in Section 6.3.

The system diagrams shown in the following section are configured in terms of installation on one side of the highway. However, provision is made for crossing the highway at interchanges so that cameras can be located on both sides of the highway. As part of the design criteria, the cameras on both sides of the highway are to be located at intervals of approximately 1.6km. In order to minimize the costs of crossovers at the interchanges, it is suggested that the cameras on the side of the highway opposite to the main transmission line, should be located within a reasonable distance of the interchanges.

The system has been designed not only to meet the present requirements of Stage I but also to allow for later extension to Stage II of the full Highway 401 Corridor System. To provide for this, the video signal is fed into the main transmission cable through a coupler or combiner. The currently available reliable (over 100,000 hours life expectancy) low-cost lasers operate on shortwavelengths in the 840 nM wavelength range. At those wavelengths, the attenuation of high quality fiber is equal to or better than 3 db per kilometre loss. The fiber characteristics at longer wavelengths, say 1300 nM, are such that the attenuation is substantially lower, e.g. 1.3 dB per kilometre. The electro-optic devices required

for longer wavelengths are currently available but they are more costly and their reliability at this stage is not acceptable. However, the current high R & D effort suggests that these problems will be solved in the next three years. The use of a coupler, therefore, permits simple expansion of the system to accommodate longer wavelengths in Stage II on the same fiber installed in Stage I. Hence, we recommend that a two-window graded index fiber be used in the proposed configuration.

The video signals from all 24 cameras in Stage I are available in the control centre at any time. Since there will be 8 T.V. monitors in the centre, a baseband switch is needed for selection of the camera signals required for display.

The baseband switch is suitable for application to the Highway 401 Corridor and other similar traffic systems. However, it is limited in terms of the distance over which it can be used to transmit signals because of two factors: linearity of lasers and noise introduced by repeaters. These limitations become important over distances greater than about 140km, which is much greater than the distances in Stages I, II or III of the MTC program.

The cost estimates for the baseband system have been derived from current estimates obtained from a number of suppliers. The detailed estimates for the various subsystems are provided in Section 11.1.3. These figures cover material and installation of the electronic and electro-optic subsystems and the cost of fiber cables for the baseband video system. They exclude the costs of power, voice and data systems and installation of the fiber cable, which are common to the alternative video systems and hence are discussed elsewhere in the report.

The estimated cost per metre of highway is $24.20 for material and $1.31 for installation.

It should be noted that the precise number of splices required will be determined during the future system design phase of the project if MTC decides to undertake it. ATS has used 250 splices as a conservative estimate in the calculations so that this element is taken into consideration in the system cost.

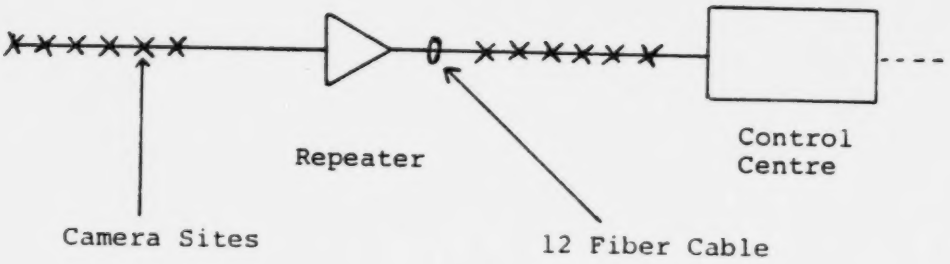
This figure has been arrived at from the following assumptions:

	No. of Splices
Data Drop and Insert Splices	68
Camera Sites	92
Assumed Additional In Line Splices	90
	250

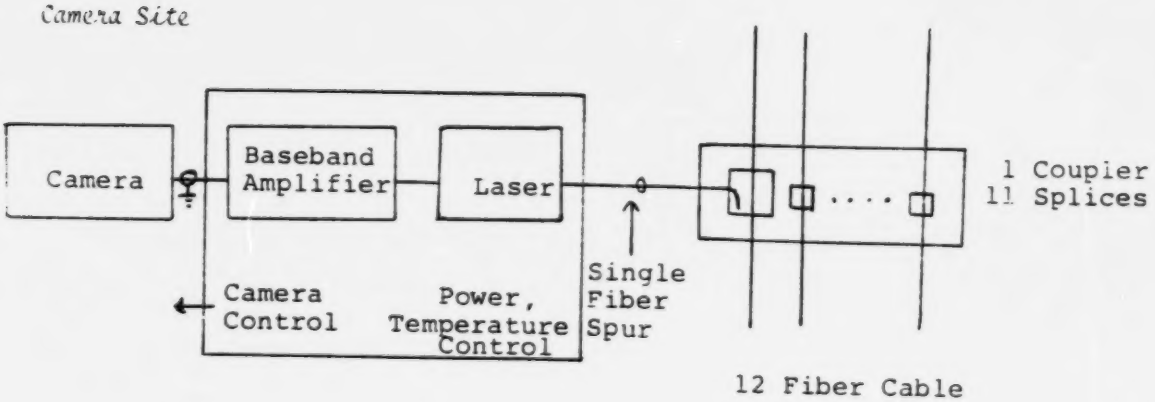
Very few connectors have been used in the system designs. Splices are recommended instead because of the requirements for the project. Detailed information on connectors is available in a study carried out by the Dept. of Communications, a copy of which has been received by Mr. Lamberto Gomes of MTC. The cost of the connectors required is insignificant and it has, therefore, not been included in the cost estimates.

11.1.2 Baseband System/One Fiber Per Camera: System Diagrams

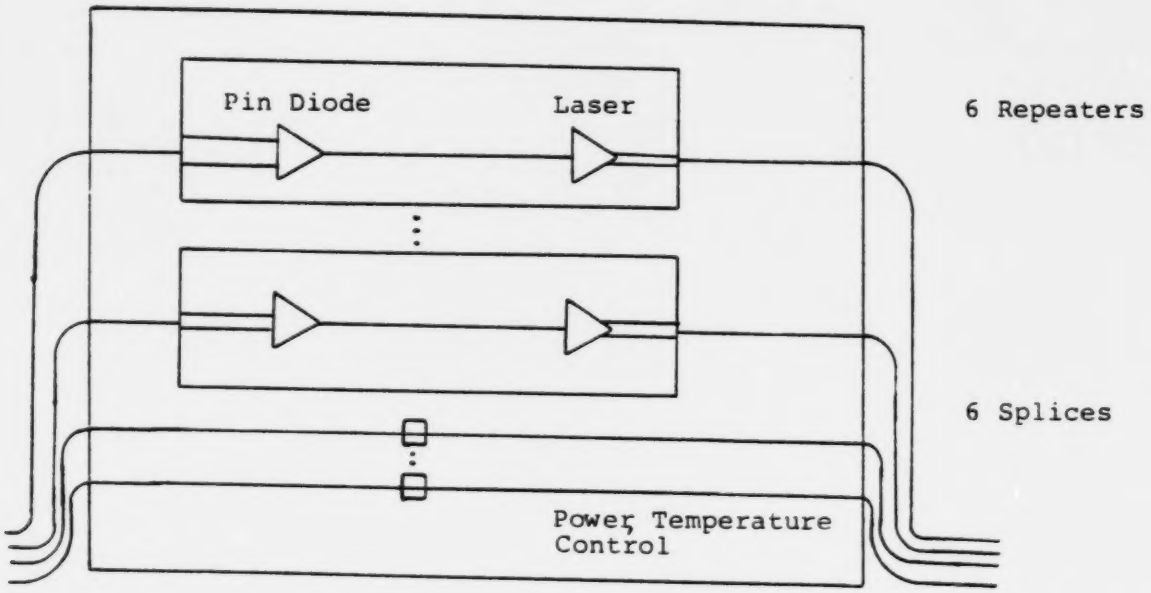
(a) *Configuration*



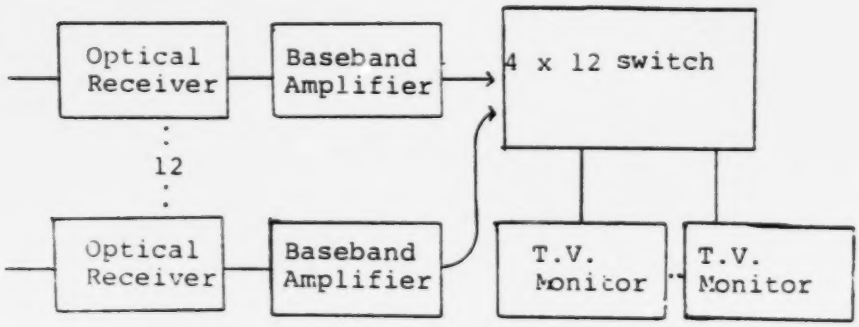
(b) *Camera Site*



(c) *Repeater Site*



(d) *Control Centre*



11.1.3 Baseband System: Cost Estimate

(a) Material

Camera Site (12)	Unit Price $	Total Price $
- Housing	600.	7,200.
- Power Supply	800.	9,600.
- Temperature Control	500.	6,000.
- Laser/Baseband Amplifier	4,000.	48,000.
- Equipment Shelf (included in housing)		
		70,800.

Repeater Site (1)		
- Housing	1,800.	1,800.
- Power Supply	1,000.	1,000.
- Temperature Control	500.	500.
- Repeater Shelf (included in housing)		
- Repeaters (6)	5,000.	30,000.
		33,300.

Control Centre (1)			
- Optical Receiver/Baseband Amp	(12)	1,000.	12,000.
- Eqpt Shelf	(1)		
- Power Supply	(1)	1,000.	1,000.
- Frame	(1)		
- Video Switch (4 x 12)	(1)	2,400.	2,400.
			15,400.

Fiber Line		Unit Price $	Total Price $
- 13km of 12 Fiber Cable		14/metre	182,000.
- 2km of 1 Fiber Cable (highway crossings, spurs)		1.50/metre	3,000.
- Splice Enclosures	(24)	250.	6,000.
- Splices	(250)	2.	500.
- Couplers	(12)	300.	3,600.
			195,100.
Total Material Cost for Configuration Shown			314,600.
TOTAL MATERIAL COST FOR STAGE I, 26km SYSTEM			$629,200.

(b) *Installation of Electronics and Electro-Optic Subsystems*

- Camera Sites (12) $1,000. per site	12,000.
- Repeater Site (1) $2,000. per repeater site	2,000.
- Control Centre (1)	3,000.
Total Installation Cost for Configuration Shown	17,000.
TOTAL INSTALLATION COST FOR STAGE I, 26km SYSTEM	$34,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystems Per Metre of Highway ..... $ 25.51

11.2 Switched Baseband System/Any Four Cameras (no blocking)

11.2.1 Description:

The switched baseband system is similar to the baseband system except that the switching function to provide selection of the camera signals, is carried out at the camera site instead of in the control centre. This means that only 4 fibers, instead of 12, are needed to carry the video signal to the control centre. However, both the quality of the signal and selectivity of cameras is maintained at the same level as for the baseband system. The advantage of this approach is that the cost of transmission using fiber cable is greatly reduced.

In order to provide for the switching function at the camera site, an optical switch must be included at the camera site to switch the laser on and off, and to feed the signal through one of the four fibers. It is fairly easy to provide for control of the optical switch and laser through the use of the data system, since this will be used anyway for camera control and for monitoring temperature and power at the site. An additional advantage of the switched baseband system is that the life of the laser will be extended by more than 60 percent thus significantly improving the reliability of the system.

As in the baseband system, couplers are also used in the switched baseband system to allow for extension by means of long wavelengths in Stage II using the 4 fiber cable installed in Stage I. The configuration shown is for installation on one side of the highway, and the same criteria for camera location in the baseband system apply to the switched baseband system.

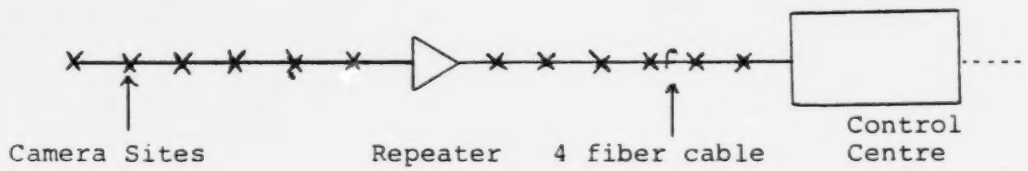
The detailed estimates for the various subsystems are provided in Section 11.2.3. As before, the figures cover material and installation of the electronic and electro-optic subsystems and the cost of fiber cables. They exclude the costs of power, voice and data systems and installation of fiber cable which are discussed elsewhere in the report.

The estimated cost per metre of highway is $16.25 for material and $1.19 for installation.

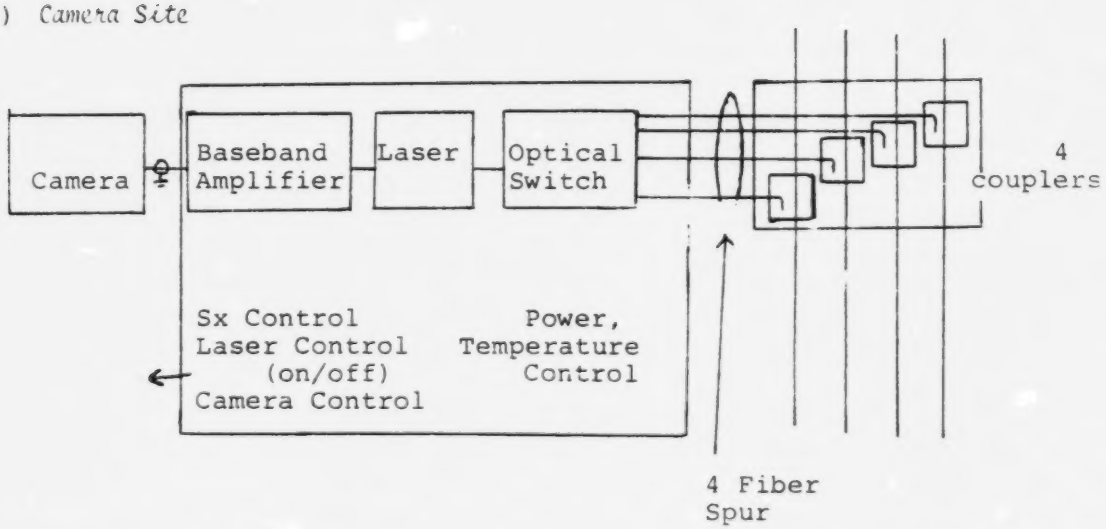
11.2.2 Switched Baseband System/Any Four Cameras (no blocking)

System Diagrams:

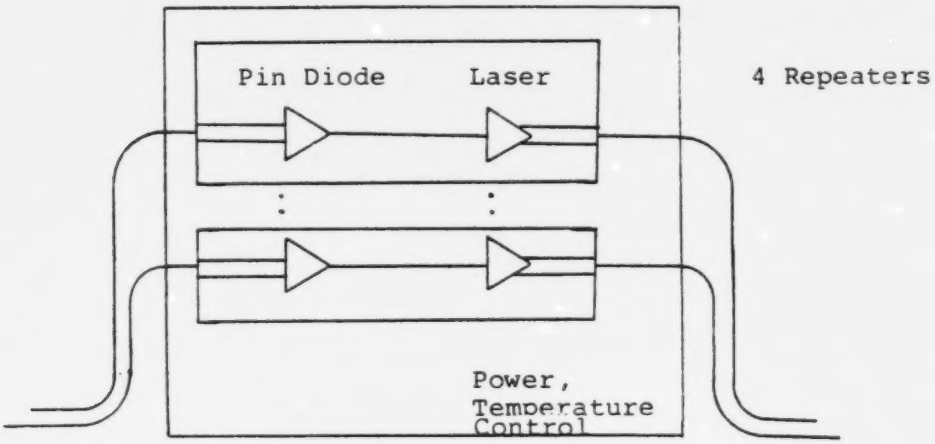
(a) *Configuration*



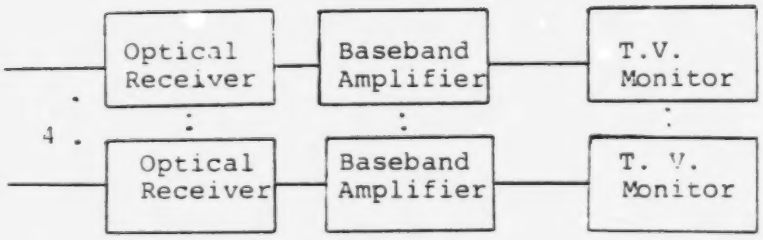
(b) *Camera Site*



(c) *Repeater Site*



(d) *Control Centre*



11.2.3 Switched Baseband System: Cost Estimate

(a) Material

Camera Site (12)	Unit Price $	Total Price $
- Housing	600.	7,200.
- Power Supply	800.	9,600.
- Temperature Control	500.	6,000.
- Laser/Baseband Amp	4,000.	48,000.
- Optical Switch (1 x 4)	600.	7,200.
		78,000.

Repeater Site (1)		
- Housing	1,800.	1,800.
- Power Supply	1,000.	1,000.
- Temperature Control	500.	500.
- Repeater (4)	5,000.	20,000.
		23,300.

Control Centre (1)		
- Optical Receiver/Baseband Amplifier (4)	1,000.	4,000.
- Shelf, Frame, Power Supply	1,000.	1,000.
		5,000.

Fiber Line		Unit Price $	Total Price $
- 13km of 4 Fiber Cable		5.60/metre	72,800.
- 2km of 4 Fiber Spur		5.60/metre	11,200.
- Splice Enclosures	(24)	250.	6,000.
- Splices	(250)	2.	500.
- Couplers	(48)	300.	14,400.
			104,900.
Total Material Cost for Configuration Shown			211,200.
TOTAL MATERIAL COST FOR STAGE I, 26km SYSTEM			$422,400.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Sites (12) $1,000. per site	12,000.
- Repeater Sites (1) $1,500. per site	1,500.
- Control Centre	2,000.
Total Installation Cost for Configuration Shown	15,500.
TOTAL INSTALLATION COST FOR STAGE I, 26km SYSTEM	$31,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystems per Metre of Highway ..... $ 17.44

11.3 Frequency Modulated Multiplex System

11.3.1 Description:

The frequency modulation technique applied in this system is widely used for long distance transmission of video signals on microwave systems around the world, and has been in use for more than 30 years. This established technology has been made use of to develop the configuration for a highly efficient video transmission system. The main advantages of frequency modulation are the increased range and the very high signal/noise ratio. The technique eliminates the problems of non-linearity, variation of light levels and fequency response, and has a characteristic of greater resistance to interference.

The baseband camera signal is fequency modulated to an Intermediate Frequency (IF) signal which is in the range 60 MHz to 80 MHz. This signal in turn is used to modulate the laser which transmits the signal to the control centre. At the control centre, the signal is detected by an optical receiver and the IF signal is amplified and filtered before being demodulated to a baseband signal and switched to a T.V. monitor.

In the configuration shown, the video signals from three camera sites are carried on the same fiber. In order to accomplish this in an effective manner, each site must have a different F.M. frequency assignment in the 60 MHz to 80 MHz range. The selection of these frequencies is critical if inter-modulation noise is to be kept to the minimum acceptable level.

The video signals from all cameras are available in the control centre at the same time, and the choice of camera is made through a baseband switch. Couplers or combiners are used in this system to combine the signals from three camera sites along a single fiber. They also provide for the extension of the system to Stage II with the use of longer wavelengths along the same fibers used in Stage I, as discussed for the baseband system.

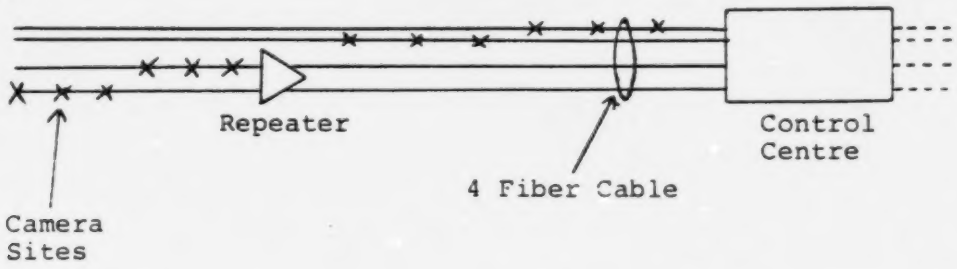
The configuration shown refers to installation on one side of the highway. As before, the costs cover material and installation of electronics and electro-optic subsystems

and the cost of fiber cables. They exclude the costs of power, voice and data systems and of installation of cables which are common to all video systems discussed here.

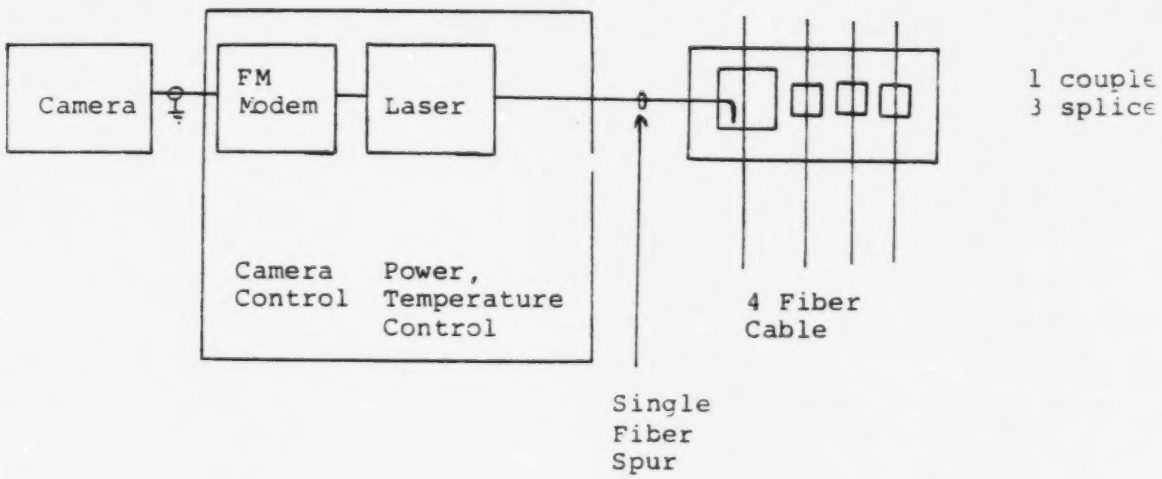
The estimated cost per metre of highway is $16.49 for material and $1.27 for installation.

11.3.2 Frequency Modulated Multiplex System: System Diagrams

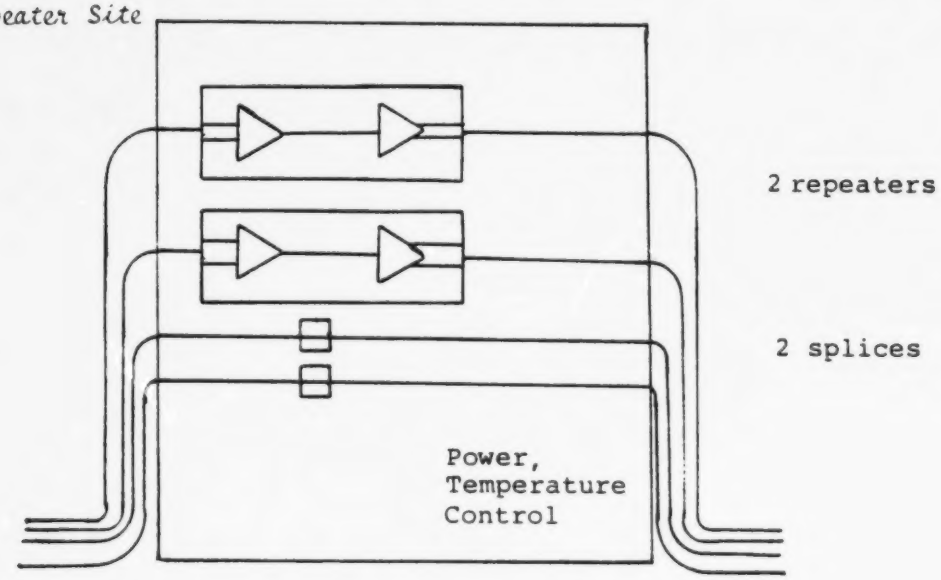
(a) *Configuration*



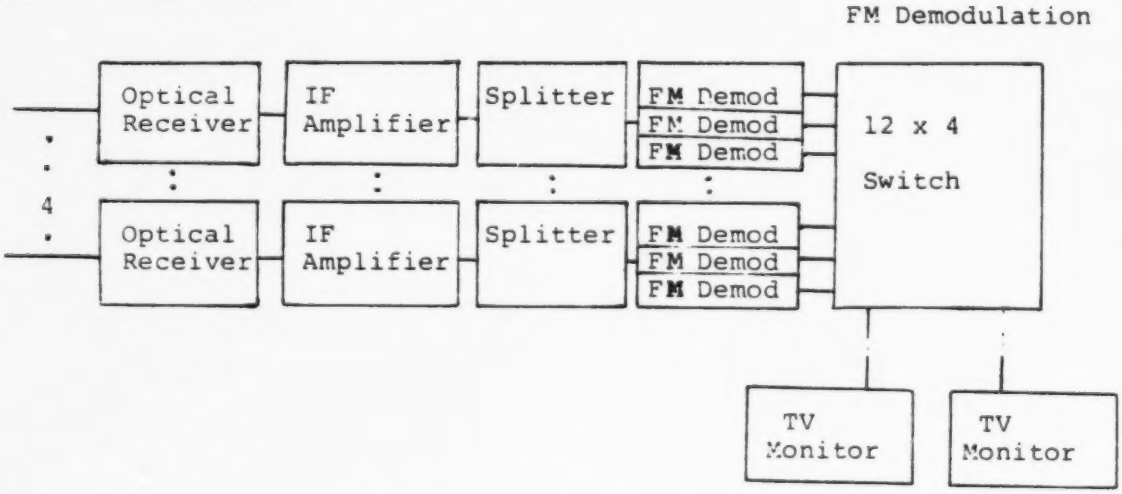
(b) *Camera Site*



(c) *Repeater Site*



(d) *Control Centre*



11.3.3 Frequency Modulated Multiplex System: Cost Estimate

(a) Material

Camera Site (12)		Unit Price $	Total Price $
- Housing		600.	7,200.
- Power Supply		800.	9,600.
- Temperature Control		500.	6,000.
- Modulator		2,000.	24,000.
- Laser		3,500.	42,000.
			88,800.
Repeater Site (1)			
- Housing		1,800.	1,800.
- Power Supply		1,000.	1,000.
- Temperature Control		500.	500.
- Repeaters (2)		5,000.	10,000.
			13,300.
Control Centre			
- Optical Receiver/IF Amplifier	4	1,000.	4,000.
- Splitter (3 way)	4	250.	1,000.
- Demodulators	12	1,500.	18,000.
- Shelf/Frame/Power	1	1,000.	1,000.
- Video Switch (4 x 12)	1	2,400.	2,400.
			26,400.

Fiber Cable		Unit Price $	Total Price $
- 13km of 4 Fiber Cable		5.60/metre	72,800.
- 2km of 1 Fiber Spur		1.50/metre	3,000.
- Splice Enclosures	(24)	250.	6,000.
- Splices	(250)	2.	500.
- Couplers	(12)	300.	3,600.
			85,900.
Total Material Cost for Configuration Shown			$214,400.
TOTAL MATERIAL COST FOR STAGE I, 26km SYSTEM			$428,800.

(b) *Installation of Electronics and Electro-Optical Subsystem*

- Camera Site (12) $1,000. per site	12,000.
- Repeater Site (1)	1,500.
- Control Centre (1)	3,000.
Total Installation Cost for Configuration Shown	$16,500.
TOTAL INSTALLATION COST FOR STAGE I, 26km SYSTEM	$33,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per Metre of Highway ..... $ 17.76

11.4 Digital System

11.4.1 Description:

With the widespread use of digital switching in the telephone industry, digital transmission has become economically attractive for voice applications. More recently, substantial reductions in the cost of fiber and electronics are making digital systems economically attractive for video transmission over long distances, e.g. more that 300km. These systems operate at 90 Mbit/s rates per fiber providing one video channel of broadcast quality. They require digital repeaters approximately every 8km. The main advantage of digital systems which make them attractive for long distance transmission, is the inherent characteristic of the technology to regenerate the video signal and eliminate distortions introduced during transmission.

The main disadvantage for application for the present project is the high cost of analog to digital conversion, and vice versa, which are required at the camera sites and control centre respectively. In addition, digital transmission requires substantially more electronic subsystems than other transmission methods, thus increasing the costs and complexity of maintenance, and reducing reliability unless redundancy is provided for.

The configuration shown is based on a 4 fiber cable with three cameras per fiber. Because of bandwidth limitations, the system does not allow for simultaneous transmission of three video signals on a single fiber, so that only one of the three signals on any given fiber can be monitored at a particular time (blocking). This limitation could be eliminated by using a 12 fiber cable at a much higher cost.

It is possible that advances in technology may lead to the development of digital cameras and monitors which will substantially alter the economics of these systems. However, this is unlikely to happen within the time frame of the present program.

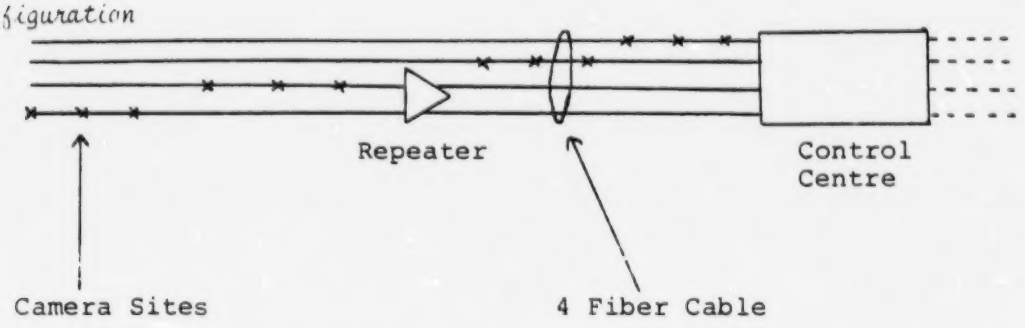
In the system shown, a video baseband signal originating at a camera is converted to a digital signal. When this signal is to be monitored in the control centre, the switch is used to route the signal via the laser to the centre. Otherwise, if a signal originating at a camera site further away from the control centre is required, the switch will be used to disconnect the local signal, and the combination of the laser and optical receiver then effectively becomes a repeater for the required signal. The video signal received at the control centre is converted to a baseband analog format and displayed on a T.V. monitor.

The cost estimates provided are based on installation on one side of the highway. They cover material and installation of electronic and electro-optic subsystems and the cost of the fiber cables, but exclude the costs of power, voice and data systems and the costs of installation of the fiber cable.

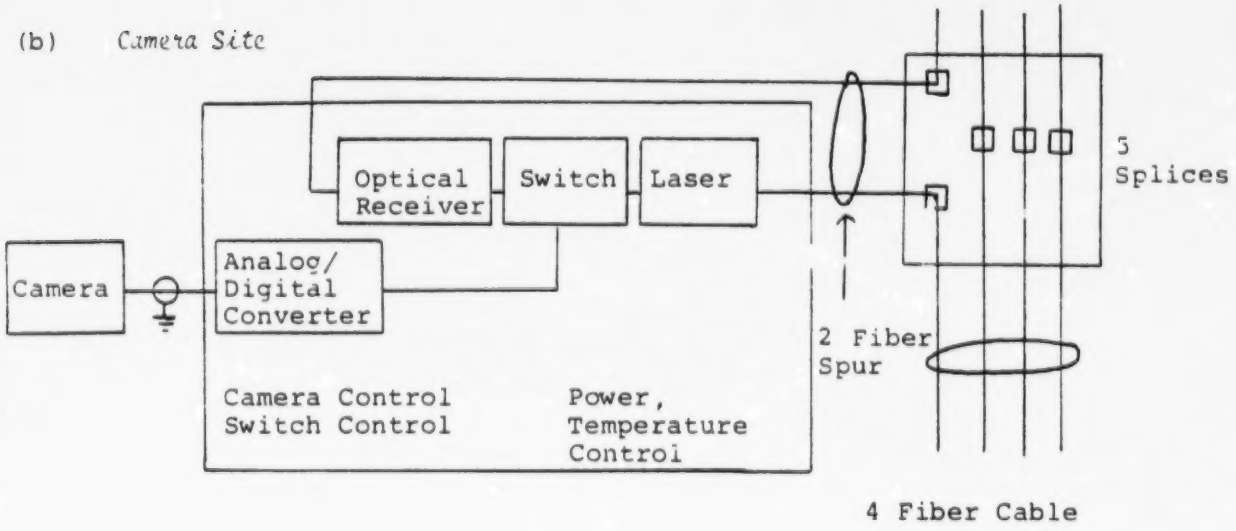
The estimated cost per metre of highway is $24.75 for material and $2.38 for installation.

3.4.2 Digital System: System Diagrams

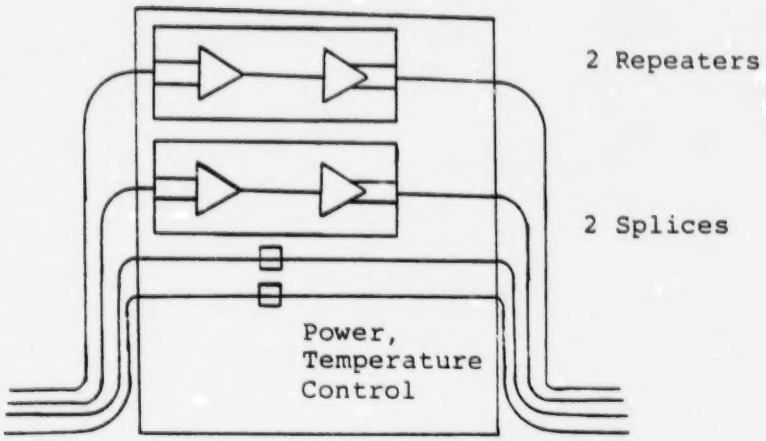
(a) *Configuration*



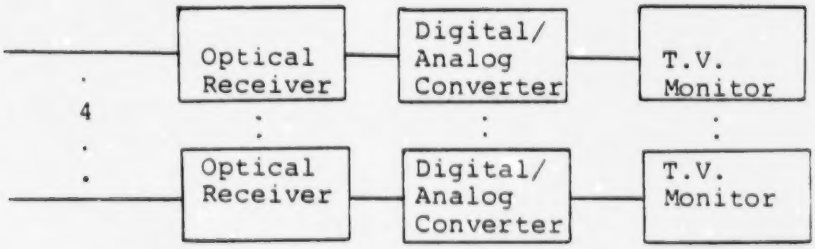
(b) *Camera Site*



(c) *Repeater Site*



(d) *Control Centre*



11.4.3 Digital System: Cost Estimate

(Note: One camera can be used at any time from a zone of 3 cameras)

(a) *Material*

	Unit Price $	Total Price $
Camera Site (12)		
- Housing	600.	7,200.
- Power Supply & Tray	2,500.	30,000.
- Temperature Control	500.	6,000.
- A/D Converter	7,000.	84,000.
- Optical Receiver, Insert and Laser Transmitter	5,000.	60,000.
		187,200.
Repeater Site (1)		
- Housing	600.	600.
- Power Supply	2,500.	2,500.
- Temperature Control	500.	500.
- Repeater Shelf (included in housing)		
- Repeaters (2)	5,000.	10,000.
		13,600.
Control Centre (1)		
- Optical Receiver (4)	1,300.	5,200.
- D/A Converter (4)	7,000.	28,000.
- Power Supply/Frame (1)	2,500.	2,500.
		35,700.

Fiber Cable		Unit Price $	Total Price $
- 13km of 4 Fiber Cable		5.60/metre	72,800.
- 3km of 2 Fiber Cable		2.80/metre	8,400.
- Splices	(250)	2.	500.
- Splice Enclosures	(12)	300.	3,600.
			85,300.
Total Material Cost for Configuration Shown			$321,800.
TOTAL MATERIAL COST FOR STAGE I, 26km SYSTEM			$643,600.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Site (12) $2,000. per site	24,000.
- Repeater (1)	2,000.
- Control Centre	5,000.
Total Installation Cost for Configuration Shown	31,000.
TOTAL INSTALLATION COST FOR STAGE I, 26km SYSTEM	$62,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per metre of Highway ..... $ 27.14

12.0 VIDEO SYSTEMS INSTALLED ON BOTH SIDES OF THE HIGHWAY

12.1 Baseband System/One Fiber Per Camera

12.1.1 Description:

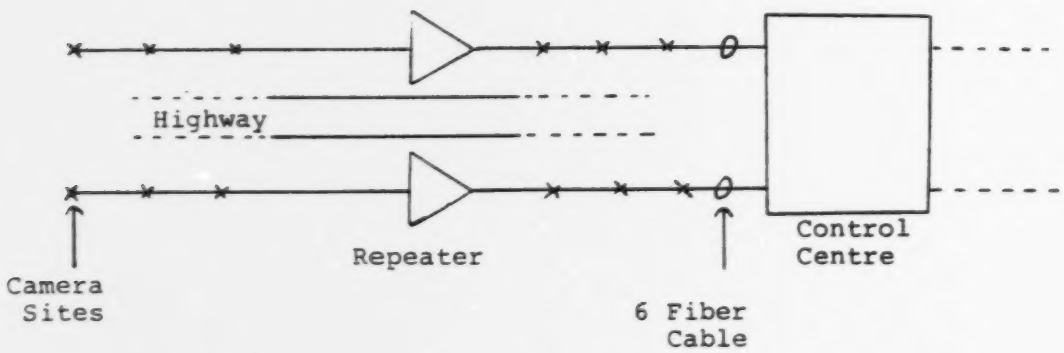
The baseband system for installation on both sides of the highway is described in this section. The technical characteristics and limitations of the system are the same as those discussed for the system installed on one side of the highway. In this application, two repeater sites are needed, one on each side of the highway, and the main transmission cable is 6 fiber instead of 12 fiber cable. In addition, the support structure (conduit and routing) is configured differently for installation on both sides of the highway.

As before, the costs shown cover material and installation of electronic and electro-optic subsystems and the cost of the fiber cable. They exclude the cost of power, voice and data systems and the cost of installation of the fiber cable.

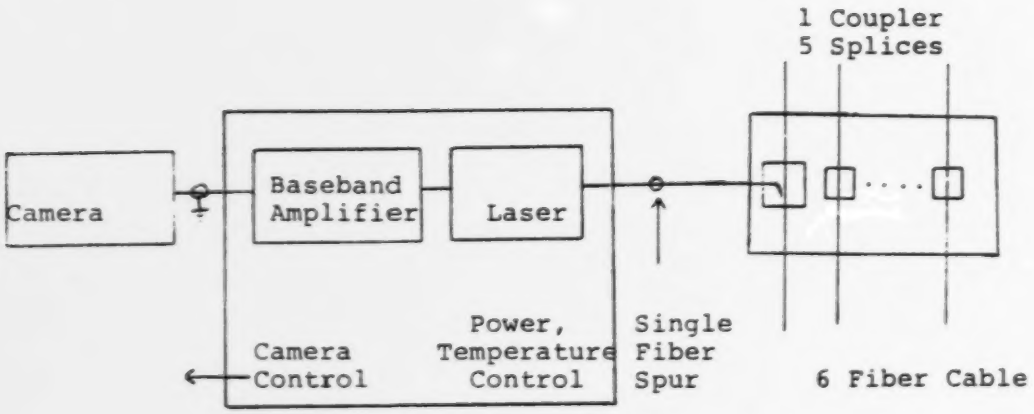
The estimated cost per metre of highway is $24.73 for material, and $1.38 for installation.

12.1.2 Baseband System/One Fiber Per Camera: System Diagrams

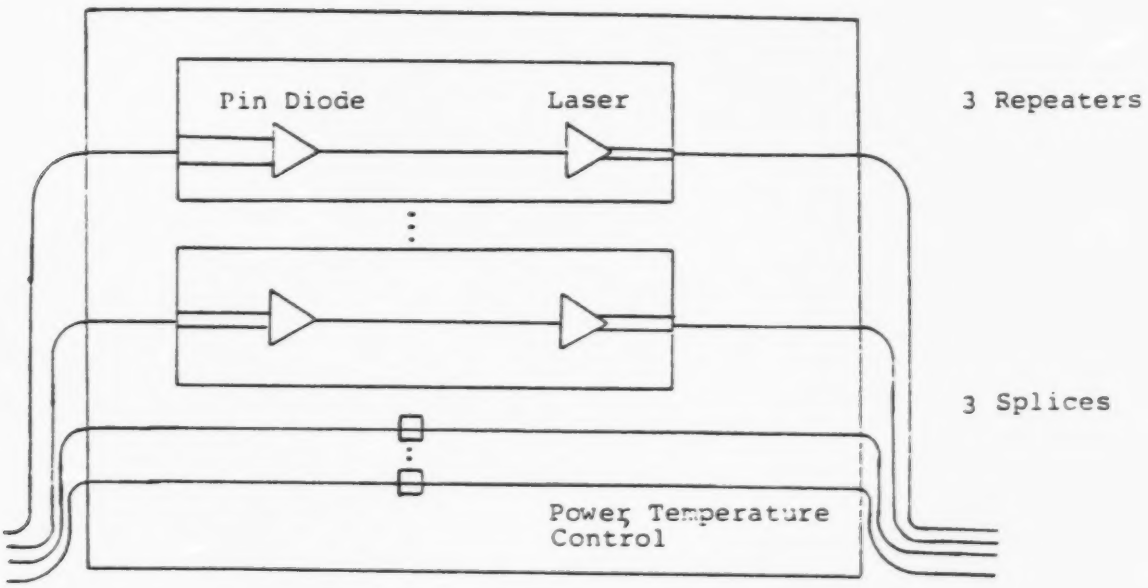
(a) *Configuration*



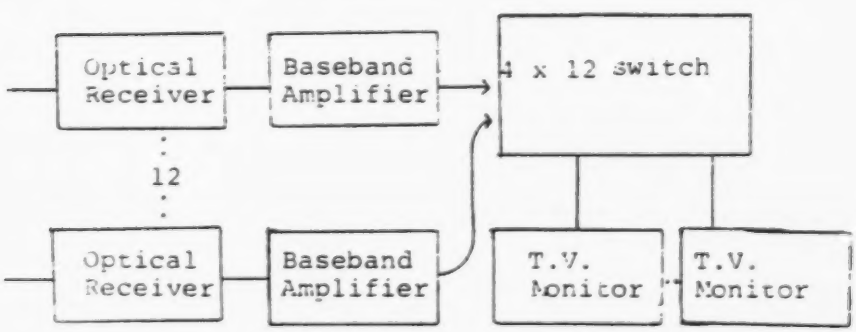
(b) *Camera Site*



(c) Repeater Site



(d) Control Centre



12.1.3 Baseband System: Cost Estimate

(a) Material

Camera Site (12)	Unit Price $	Total Price $
- Housing	600.	7,200.
- Power Supply	800.	9,600.
- Temperature Control	500.	6,000.
- Laser/Baseband Amplifier	4,000.	48,000.
- Equipment Shelf (included in housing)		
		70,800.

Repeater Site (2)		
- Housing	1,800.	3,600.
- Power Supply	1,000.	2,000.
- Temperature Control	500.	1,000.
- Repeaters (3)	5,000.	15,000.
		21,600.

Control Centre (1)			
- Optical Receiver/Baseband Amp	(12)	1,000.	12,000.
- Eqpt Shelf	(1)		
- Power Supply	(1)	1,000.	1,000.
- Frame	(1)		
- Video Switch (4 x 12)	(1)	2,400.	2,400.
			15,400.

Fiber Line		Unit Price $	Total Price $
- 26km of 6 Fiber Cable		7.80/metre	202,800.
- 1/2km of 1 Fiber Cable		1.50/metre	750.
- Splice Enclosures	(24)	250.	6,000.
- Splices	(250)	2.	500.
- Couplers	(12)	300.	3,600.
			213,650.
Total Cost of Material for Configuration Shown			$321,450.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM			$642,900.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Sites (12) $1,000. per site	12,000.
- Repeater Sites (2) $1,500. per site	3,000.
- Control Centre	3,000.
Total Cost of Installation for Configuration Shown	18,000.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM	$36,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per metre of Highway ..... $ 26.11

12.2 Switched Baseband System

12.2.1 Description:

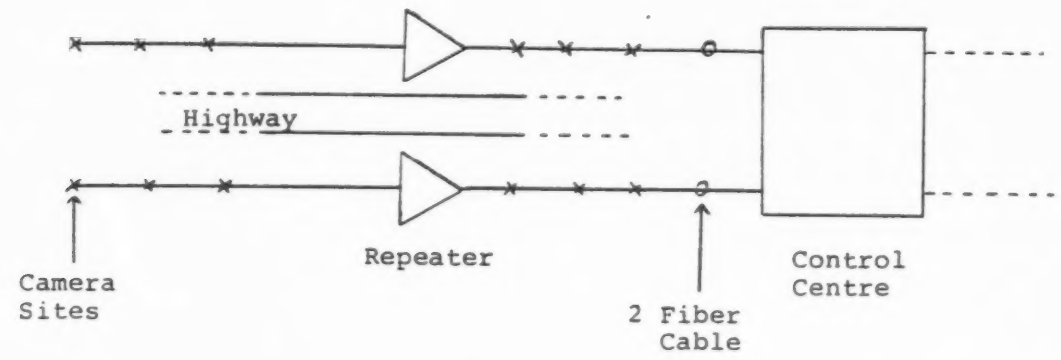
In this section, we describe the switched baseband system installed on both sides of the highway. The technical characteristics and limitations of the system are the same as those discussed for installation on one side of the highway. However, two repeater sites are needed in this case, and the main transmission cable is 2 fiber instead of 4 fiber. The support structure (conduit and routing) is also configured differently in this case.

As before the costs shown cover material and installation of electronic and electro-optic subsystems and the cost of the fiber cable. They exclude the cost of power, voice and data systems, and the cost of installation of the fiber cable.

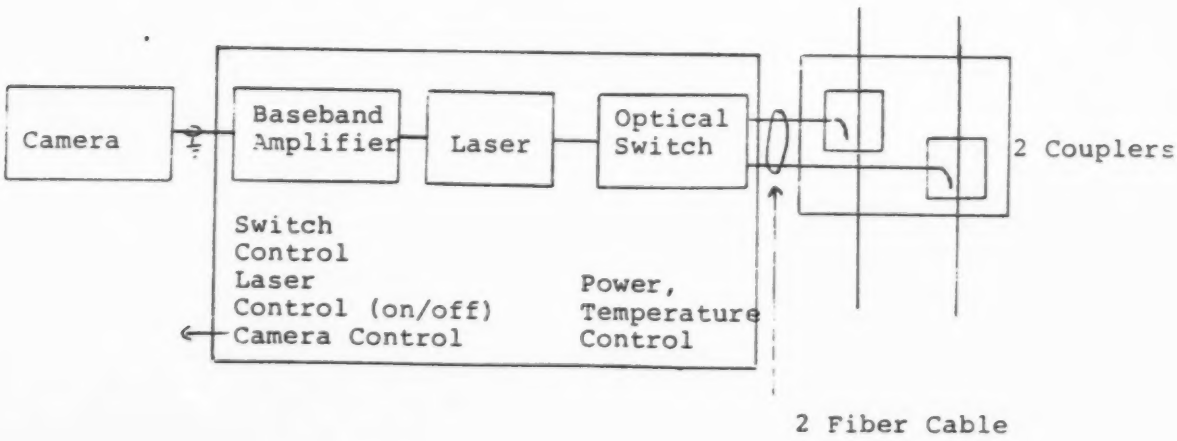
The estimated cost per metre of highway is $14.76 for material and $1.26 for installation.

12.2.2 Switched Baseband System: System Diagrams

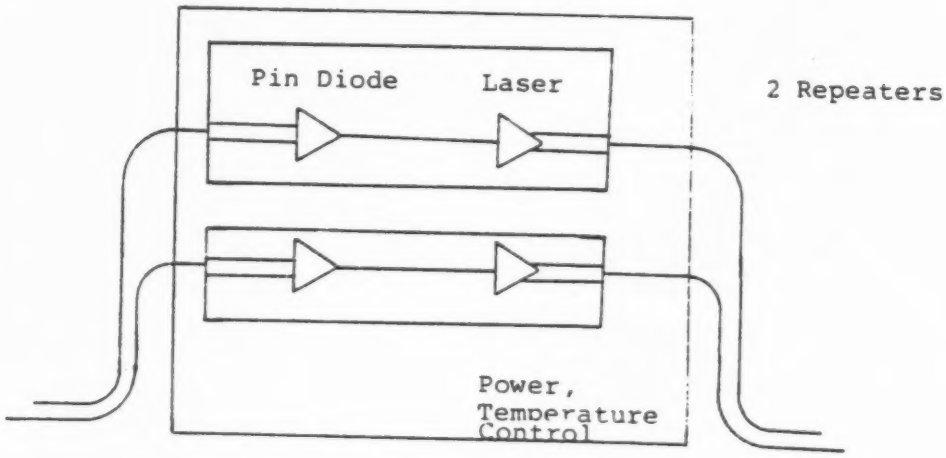
(a) *Configuration*



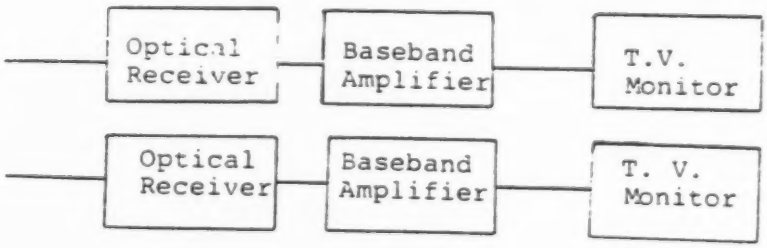
(b) *Camera Site*



(c) Repeater Site



(d) Control Centre



12.2.3 Switched Baseband System: Cost Estimate

(a) *Material*

Camera Site (12)	Unit Price $	Total Cost $
- Housing	600.	7,200.
- Power Supply	800.	9,600.
- Temperature Control	500.	6,000.
- Laser/Baseband Amp	4,000.	48,000.
- Optical Switch (1 x 2)	290.	3,480.
		74,280.

Repeater Site (2)		
- Housing	1,800.	3,600.
- Power Supply	1,000.	2,000.
- Temperature Control	500.	1,000.
- Repeater (4)	5,000.	20,000.
		26,600.

Control Centre (1)		
- Optical Receiver/Baseband Amp (4)	1,000.	4,000.
- Shelf, Frame, Power Supply	1,000.	1,000.
		5,000.

Fiber Line		Unit Price $	Total Price $
- 26km of 2 Fiber Cable		2.80/metre	72,800.
- Splice Enclosures	(24)	250.	6,000.
- Combiners	(24)	300.	7,200.
			86,000.
Total Cost of Material for Configuration Shown			$191,880.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM			$383,760.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Sites (12) $1,000. per site	12,000.
- Repeater Sites (2) 1,200. per site	2,400.
- Control Centre	2,000.
Total Cost of Installation of Configuration Shown	16,400.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM	$ 32,800.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per Metre of Highway ..... $ 16.02

12.3 Frequency Modulated Multiplex System

12.3.1 Description:

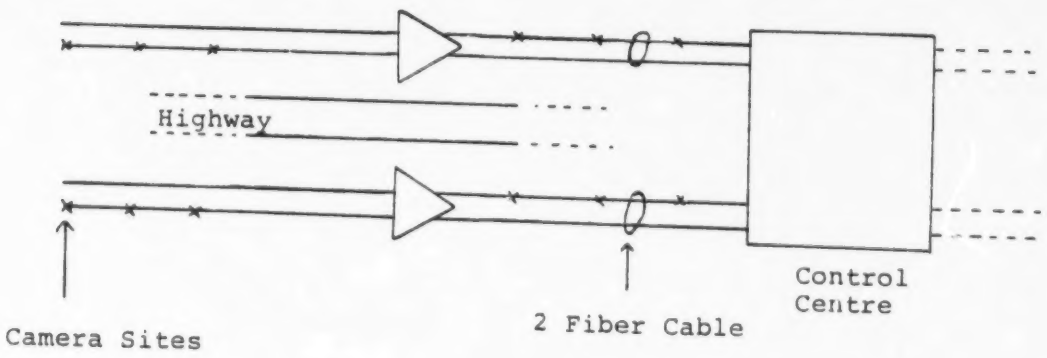
The F.M. multiplex system installed on both sides of the highway has the same technical characteristics and limitations as the system installed on one side of the highway. Two repeaters sites are needed in this case and the main transmission fiber cable is 2 fiber instead of 4 fiber. The support structure (conduit and routing) is also configured differently in this case.

As before, the costs shown cover material and installation of electronic and electro-optic subsystems as well as the cost of the fiber cable. They exclude the cost of power, voice and data systems and the cost of installation of the fiber cable.

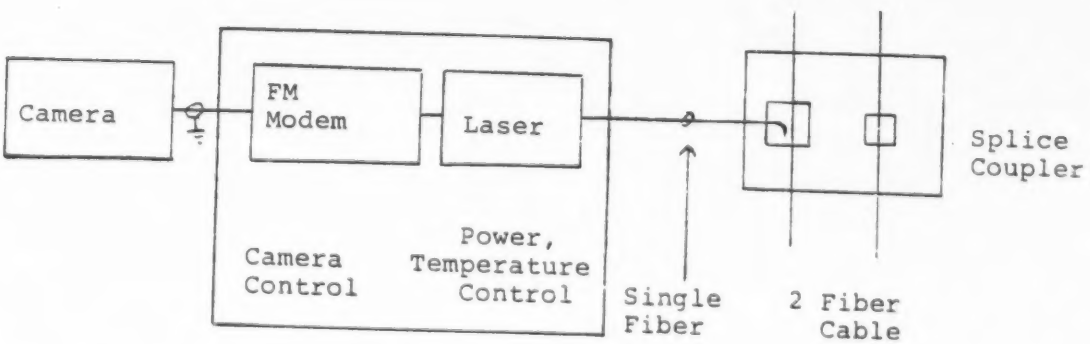
The estimated cost per metre of highway is $16.57 for material and $1.34 for installation.

12.3.2 Frequency Modulated Multiplex System: System Diagrams

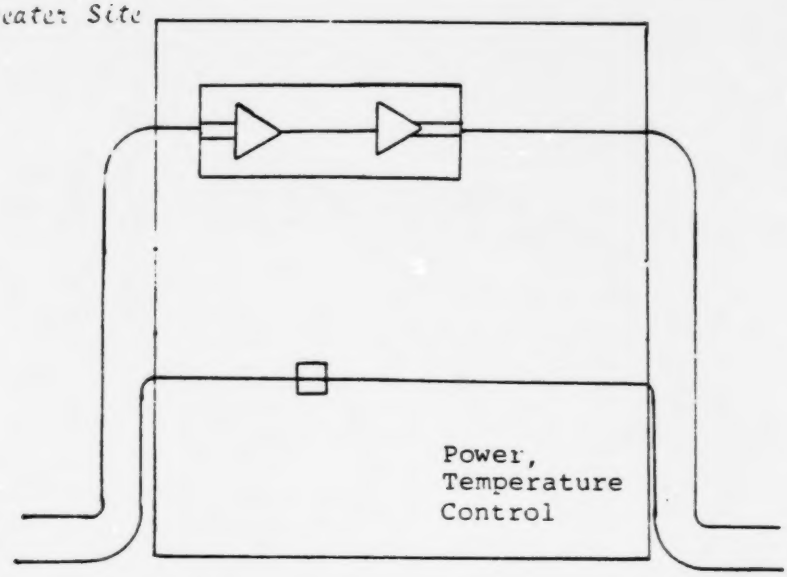
(a) *Configuration*



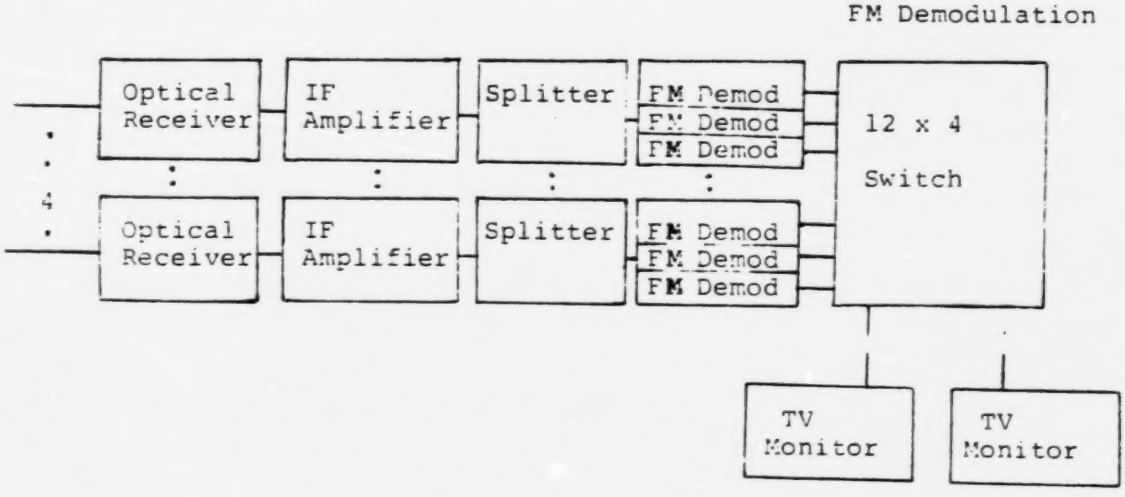
(b) *Camera Site*



(c) Repeater Site



(d) Control Centre



12.3.3 Frequency Modulated Multiplex System: Cost Estimate

(a) *Material*

Camera Site (12)	Unit Price $	Total Price $
- Housing	600.	7,200.
- Power Supply	800.	9,600.
- Temperature Control	500.	6,000.
- Modulator	2,000.	24,000.
- Laser	3,500.	42,000.
		88,800.

Repeater Site (2)		
- Housing	1,800.	3,600.
- Power Supply	1,000.	2,000.
- Temperature Control	500.	1,000.
- Repeaters (2)	5,000.	10,000.
		16,600.

Control Centre			
- Optical Receiver/IF Amplifier	(4)	1,000.	4,000.
- Splitter (3 way)	(4)	250.	1,000.
- Demodulators	(12)	1,500.	18,000.
- Shelf/Frame/Power	(1)	1,000.	1,000.
- Video Switch (4 x 12)	(1)	2,400.	2,400.
			26,400.

Fiber Line		Unit Price $	Total Price $
- 26km of 2 Fiber Cable		2.80/metre	72,800.
- 1/2km of 1 Fiber Cable		1.50/metre	750.
- Splice Enclosures	(24)	250.	6,000.
- Splices	(250)	2.	500.
- Combiners	(12)	300.	3,600.
			83,650.
Total Cost of Material for Configuration Shown			$215,450.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM			$430,900.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Sites(12) $1,000. per site	12,000.
- Repeater Sites (2) 1,200 per site	2,400.
- Control Centre	3,000.
Total Cost of Installation for Configuration Shown	17,400.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM	$34,800.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per Metre of Highway ..... $ 17.91

12.4 Digital System

12.4.1 Description:

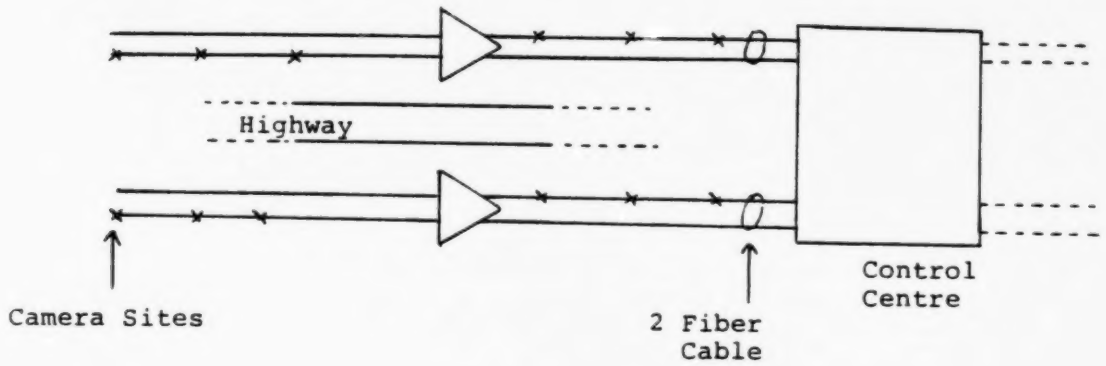
The digital system installed on both sides of the highway has the same technical characteristics and limitations as that for installation on one side of the highway. Two repeater sites are needed in this case and the main transmission fiber cable has 2 fibers instead of 4. The support structure (conduit and routing) is also configured differently.

As before, the costs shown cover material and installation of electronic and electro-optic subsystems as well as the cost of the fiber cable. They exclude the cost of power, voice and data systems and the cost of installation of the fiber cable.

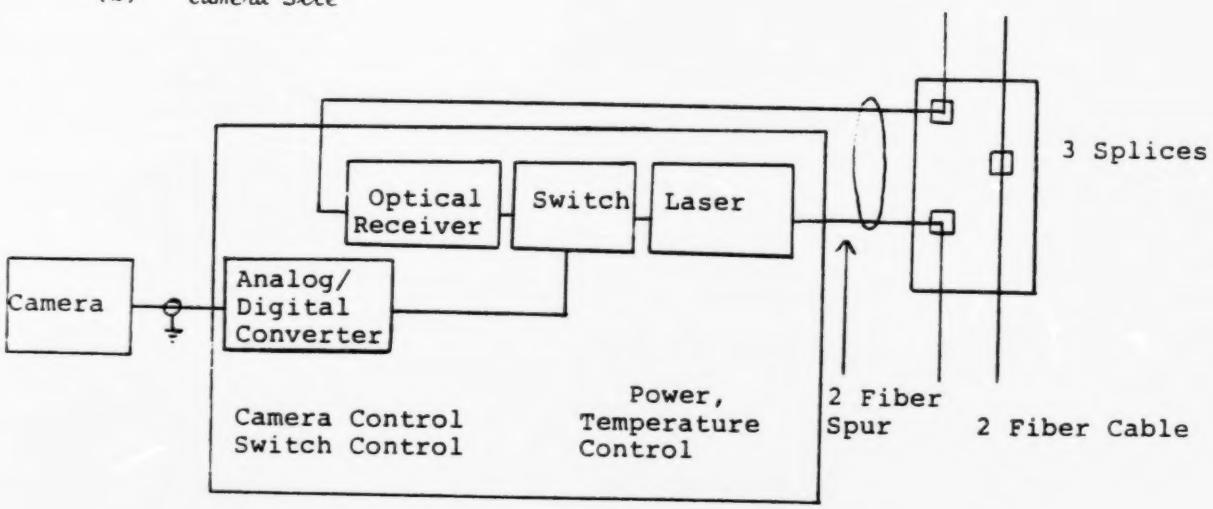
The estimated cost per metre of highway is $24.44 for material and $2.46 for installation.

12.4.2 Digital System: System Diagrams

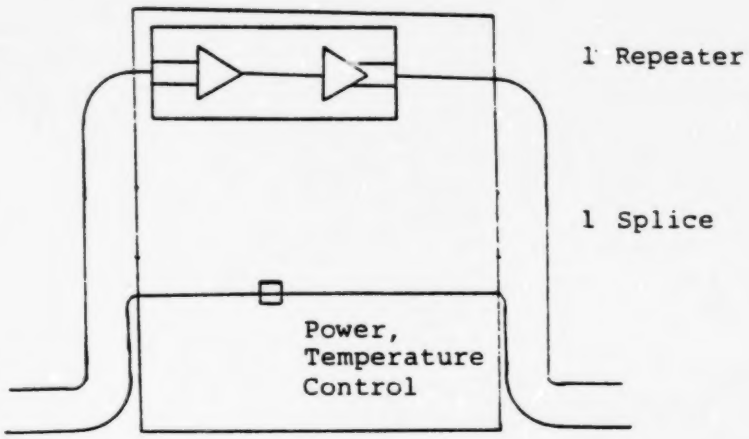
(a) *Configuration*



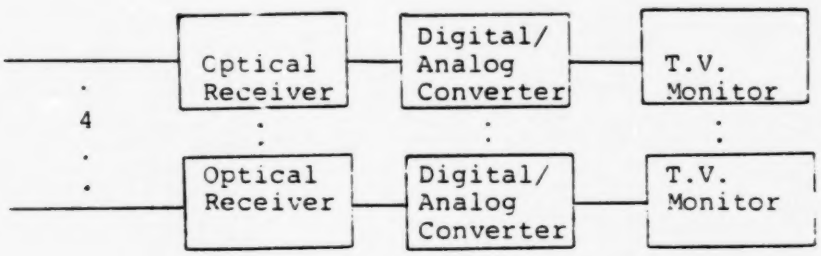
(b) *Camera Site*



(c) Repeater Site



(d) Center Cable



12.4.3 Digital System: Cost Estimate

(a) *Material*

Camera Site (12)	Unit Price $	Total Price $
- Housing	600.	7,200.
- Power Supply & Tray	2,500.	30,000.
- Temperature Control	500.	6,000.
- A/D Converter	7,000.	84,000.
- Optical Receiver, Insert and Laser Transmitter	5,000.	60,000.
		187,200.

Repeater Site (2)		
- Housing	600.	1,200.
- Power Supply	2,500.	5,000.
- Temperature Control	500.	1,000.
- Repeaters (2)	5,000.	10,000.
		17,200.

Control Centre (1)			
- Optical Receiver	(4)	1,300.	5,200.
- D/A Converter	(4)	7,000.	28,000.
- Power Supply/Frame	(1)	2,500.	2,500.
			35,700.

Fiber Line	Unit Price $	Total Price $
- 26km of 2 Fiber Cable	2.80/metre	72,800.
- 1/2km of 1 Fiber Cable	1.50/metre	750.
- Splices (250)	2.	500.
- Splice Enclosures (12)	300.	3,600.
		77,650.
Total Cost of Material for Configuration Shown		$317,750.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM		$635,500.

(b) *Installation of Electronics and Electro-Optic Subsystem*

- Camera Sites (12) $2,000. per site	24,000.
- Repeater (2) 1,500 per site	3,000.
- Control Centre	5,000.
Total Cost of Installation for Configuration Shown	$32,000.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM	$64,000.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per metre of Highway ..... $ 26.90

13.0 DATA SYSTEM ON FIBER

13.1 Description:

The fundamental bit rate for the data system on fiber is 1.544 Mbit/s.* This system as shown is used on fiber but it is also suitable for use on four wire copper network.

The generalized configuration shown refers to installation on one side of the highway, East or West of the control centre. For installation on both sides of the highway, the configuration is similar, except that the total number of basic interface units is increased. This is done to provide flexible access to the data network from the numerous changeable message signs, camera sites and traffic detection stations.

The proposed system makes use of highly reliable and low cost electro-optic components. These include Light Emitting Diodes (LED) for optical transmitters and PIN Diodes for optical receivers which have a life expectancy of more than 300,000 hours.

The numerous data collection and control points, that is changeable messages signs, camera sites and traffic detection stations, are each connected to a basic interface repeater unit. Because of the very large number (250) of such data collection and control points, it is impractical from a maintenance and operations point of view to have the required electronics dispersed along the highway. Hence, we propose that the highway be segmented into approximately 0.4km reach zones for each of the access points on the data bus. All of the separate data messages within a given zone are then collected using part of the 19 gauge copper cable to be installed for the voice and power system, and taken to a single basic interface repeater unit. This will provide a network which is much easier to operate and maintain.

At the basic interface unit, the data are dropped and added, and multiplexed and de-multiplexed, for transmission or reception along the data bus. Because of

the design of the proposed system and high bit rates, the extension to Stage II of the program would be greatly simplified.

The costs shown cover material and installation of electronic and electro-optic subsystems and the cost of the fiber used. Because of the number of basic interface repeater units used, and the much lower bandwidths required compared to video systems, the type of fiber needed for this application is low cost. Moreover, in order to keep the costs of installation low, it is suggested that the fibers used for the data system be incorporated in the fiber cable made for the video system requiring high quality fiber. The costs of installation of the fiber cable are discussed elsewhere in the report.

For installation on one side of the highway, the cost per metre of highway is $5.98 for material and $2.61 for installation. For installation on both sides of the highway, the cost per metre of highway is $8.40 for material and $2.61 for installation.

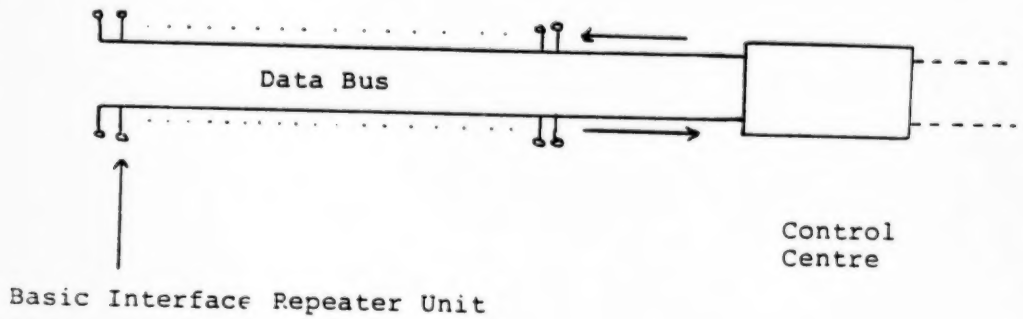
The 1.544 MBit/s data rate system was selected for the MTC data application for the following reasons:

1. Mature technology;
2. Low cost;
3. Future MTC requirements for data.

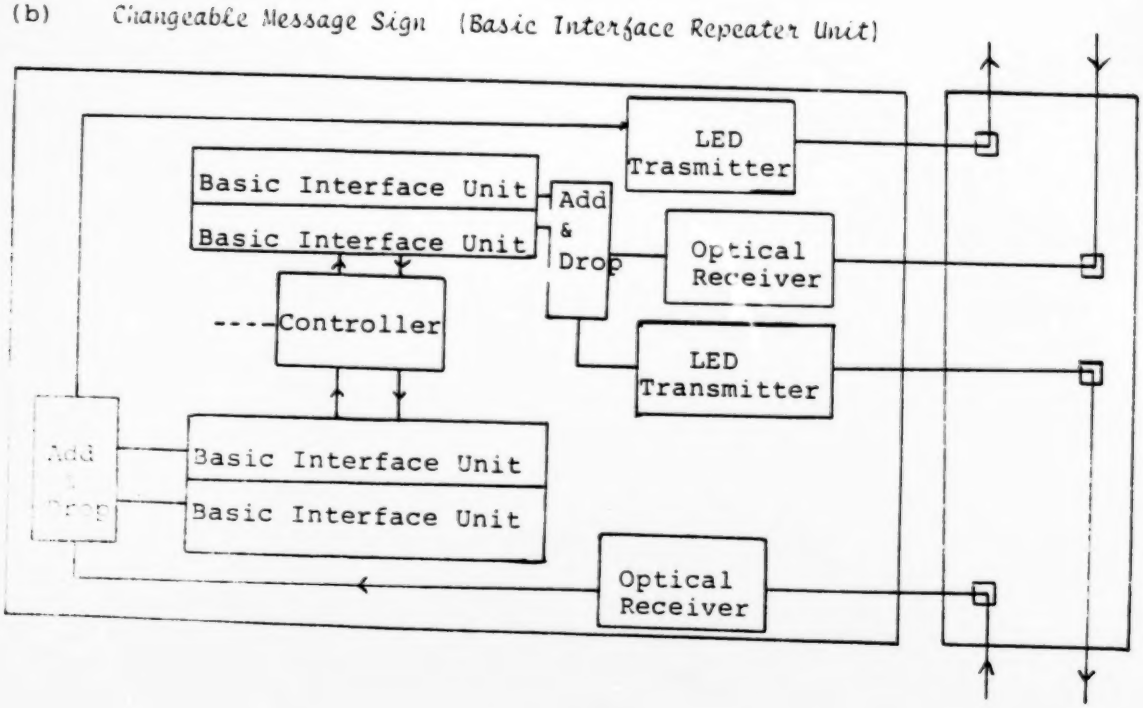
*T1 system

13.2 Data System on Fiber: System Diagrams

(a) *Configuration*



(b) *Changeable Message Sign (Basic Interface Repeater Unit)*



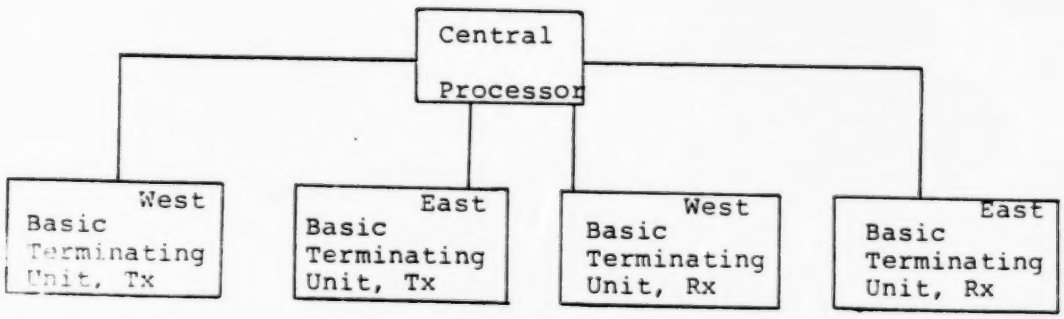
(c) *Detector Station*

Same as in (b)

(d) *Ramp Control*

Same as in (b)

(e) *Control Centre*


Central Processor
West Basic Terminating Unit, Tx
East Basic Terminating Unit, Tx
West Basic Terminating Unit, Rx
East Basic Terminating Unit, Rx

13.3 Data System on Fiber: Cost Estimate, One Side of Highway

- Co-located with Controllers or Camera Sites, Power provided to those sites
- 24 Drop and Inserts Assumed per 13km Link of System for One Side of Highway

(a) Material

Drop and Insert (24)

For C.M.C., Vehicle Detectors, Ramp Control and Camera Control

	Unit Price $	Total Price $
- Optical Interface and Common Equipment (LED/PIN) (24)	2,500.	60,000.
- Basic Interface Unit Add/Drop (24)	200.	4,800.
		64,800.

Control Centre

- Basic Terminating Unit	(1)	3,000.	3,000.
- Interface Units	(24)	200.	4,800.
			7,800.

Fiber Cable (Incremental Cost to Video Fiber Cable)	Unit Price $	Total Price $
- 13km, 2 Fibers, 6 dB/km 200 MHz per km	.40/metre	5,200.
Total Cost of Material for Configuration Shown		77,800.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM		$155,600.

(b) *Installation of Electronics and Electro-Optic Subsystem for Data Network*

- Changeable Message Signs 19 sites @ $1,000. per site	19,000.
- Camera Sites, Control and Monitoring 24 sites @ $700. per site	16,800.
- Traffic Detection Stations 64 sites @ $500. per site	32,000.
TOTAL COST OF INSTALLATION FOR CONFIGURATION SHOWN	$67,800.

Estimated Cost of Material and Installation of Electronics and Electro-Optic Subsystem, per Metre of Highway ..... $ 8.59

13.4 Data System on Fiber: Cost Estimate, Both Sides of Highway

- Co-located with Controllers or Camera Sites, power provided to those sites
- 16 drop and inserts assumed per 13km of system per side of highway.

(a) Material

Drop and Insert (16)

For C.M.S., Vehicle detectors, ramp control, and camera control.

	Unit Price $	Total Price $
- Optical Interface and Common Equipment (LED/PIN) (16)	2,500.	40,000.
- Basic Interface Unit Add/Drop (16)	200.	3,200.
		43,200.

Control Centre

- Basic Terminating Unit (1)	3,000.	3,000.
- Interface Units (16)	200.	3,200.
		6,200.

Fiber Cable (Incremental Cost to Video Fiber Cable)

- 13km, 2 fibers, 6dB/km 200 MHz per km	0.40/metre	5,200.

	Total Price $
Total Cost of Material for Configuration Shown	$ 54,600.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM	$218,400.

(b) *Installation Costs of Electronics and Electro-Optic Subsystems for Data Network*

- Changeable Message Signs 19 sites @ $1,000. per site	19,000.
- Camera Sites, Control and Monitoring 24 sites @ $700. per site	16,800.
- Traffic Detection Stations 64 sites @ $500. per site	32,000.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM	$67,800.

Estimated Cost of Material and Installation of Electronics and Electro-Optic subsystem, per Metre of Highway ..... $ 11.00

14.0 DATA SYSTEM ON COPPER

14.1 Description:

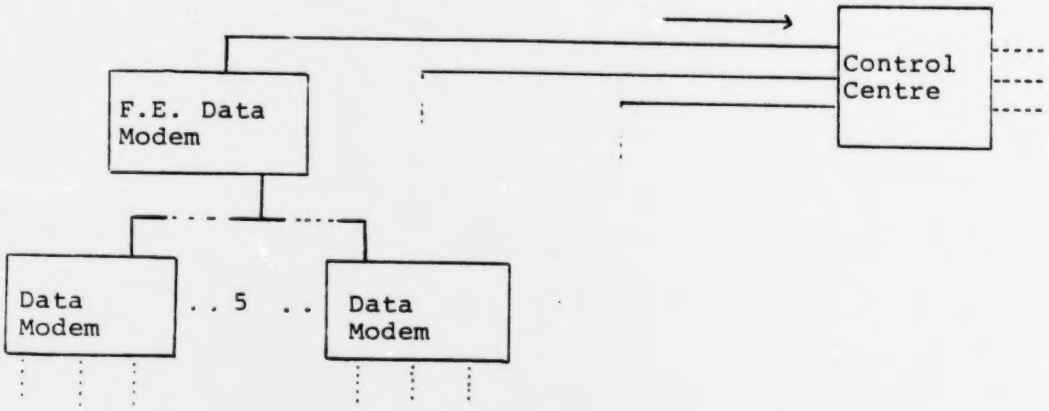
The system described for data using fibers can also be configured for data using copper conductors in a four wire network. This would require a repeater every km and the system would operate at a maximum rate of 1.5 Mbit/s. Data drop and insert would take place at the repeater points. Since this system has already been described in the case of data on fiber, it has not been considered here but it is certainly an option that is available if required.

The configuration shown is a traditional network on paired copper. The main disadvantage of this approach is that the conventional data buses can only support a limited number of data terminals. Given this limitation, a front end data modem can support up to five data modems, and it will operate at a maximum rate of 9.6 kbit/s. This limitation is due to technical problems, such as ground loops and oscillations. Hence a customized line conditioning, consisting of adding equalization and installing isolation transformers at node points, is required to overcome some of these problems.

The cost of material and installation is the same for installation on one or both sides of the highway. The cost per metre of highway is estimated to be $5.59 for material and $3.03 for installation.

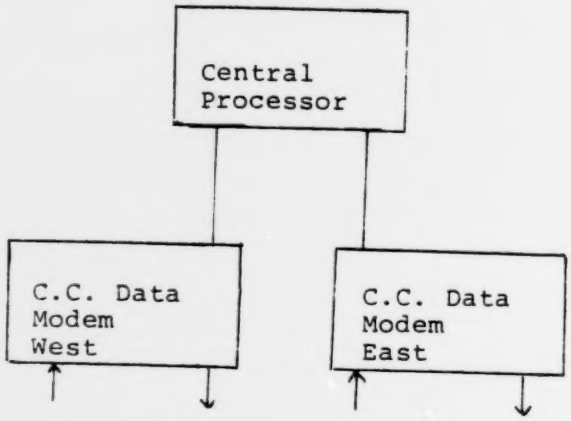
14.2 Data on Copper Pairs: System Diagrams

(a) *Configuration*



- 4 Copper Conductors per Tx/Rx Modem

(b) *Control Centre*



14.3 Data on Copper Pairs: Cost Estimate

(a) *Material*

Main Drop and Insert Stations (3)	Unit Price $	Total Price $
- Front End Modems	4,000.	12,000.
Drop and Insert Stations (16)		
- Front End Modems	800.	12,800.
Copper Line Costs		
- 12 Conductors 19 Ga (part of 11 pair Copper Cable) 13km plus 2km for spurs	0.80/metre	9,600.
- Terminators (16)	120.	1,920.
		11,520.
Total Cost of Material for Configuration Shown		36,320.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM		$145,280.

(b) *Installation Costs of Electronics Subsystems*

- Main Drop and Insert Modems 12 sites @ $1,200. per site	14,400.
- Drop and Insert Stations 64 @ $600. per site	38,400.
- Line Conditioning Coils and Equalization	26,000.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km System	$78,800.

Estimated Cost of Material and Installation of
Electronic Subsystems per Metre of Highway .....$ 8.62

15.0 VOICE SYSTEM

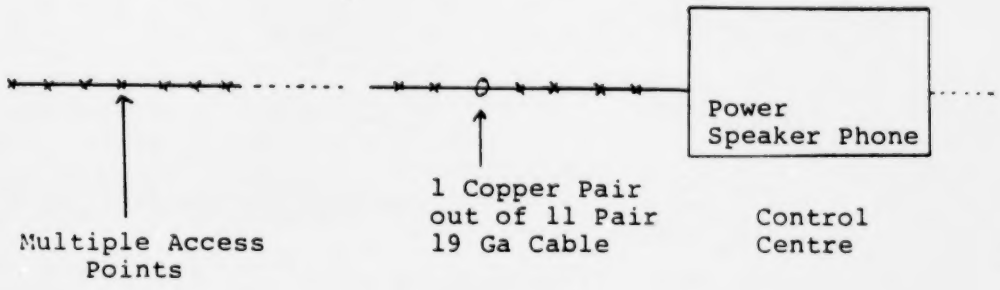
15.1 Description:

The purpose of this system is to provide a communication link for maintenance, installation and overall system operation. A 19 gauge copper pair wire would be dedicated for this purpose with a multi-party access at any point in the overall system, to maintain communications between access points as well as with the control centre. We suggest that separate power should be provided for this application to maintain an even higher degree of reliability than the other parts of the overall system, e.g. video, data.

The estimated cost of the system for installation on both sides of the highway per metre of highway is $0.50 for material and $0.22 for installation. For installation on one side of the highway, the figures are $0.31 and $0.14 respectively.

15.2 Voice System - Order Wire For Maintenance: System Diagrams

Configuration



15.3 Voice System Order Wire for Maintenance: Cost Estimate

(a) *Material*

Incremental Cost of Copper Pair	Unit Price $	Total Price $
- 13km @	.14/metre	1,820.
Cable Placement Included in Cable Placement Costs		
- Assume 70 jacks Installed		700.
- 48V Power at Control Centre		2,300.
- Speaker Phone at Control Centre		600.
Total Cost of Material for Configuration Shown		5,420.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM (Both Sides of Highway)		$12,980.
TOTAL COST OF MATERIAL FOR STAGE I, 26km SYSTEM (One Side of Highway)		$ 7,940.

(b) *Installation of Auxiliary Equipment*

- Sockets, 70 @ $15. per socket	1,050.
- Control Centre, Power and Speaker Phone System	1,500.
Total Installation Cost for Configuration Shown	2,550.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM (Both sides of Highway)	5,700.
TOTAL COST OF INSTALLATION FOR STAGE I, 26km SYSTEM (One side of Highway)	3,600.

Estimate of Cost of Material and Installation per metre of Highway:

Both Sides of Highway	.....	$ 0.72
One Side of Highway	.....	$ 0.44

16.0 POWER SYSTEM

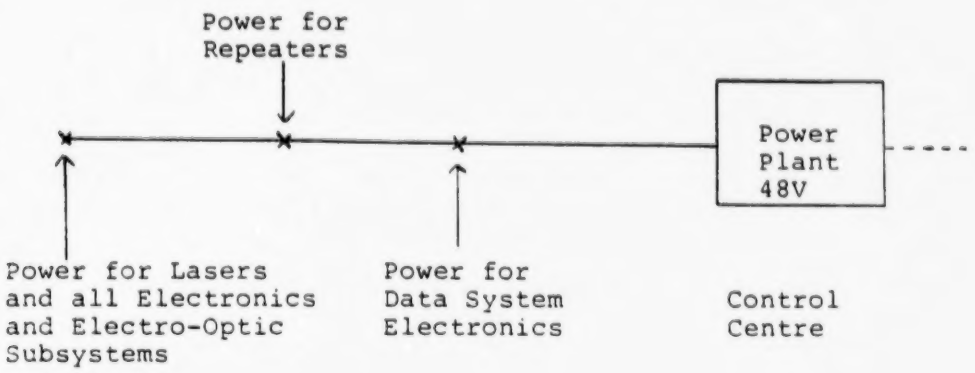
16.1 Description:

In order to increase the reliability and maintenance safety of the transmission systems for video, data and voice, an on-line powering system is recommended. A 48V power plant will be installed at the control centre and one pair of 19 gauge copper of the general purpose copper cable, will be used for power distribution to all the electronic and electro-optic subsystems operating on the highway.

The estimated cost per metre of highway is $0.47 for material on both sides of the highway and $0.33 for installation on one side of the highway.

16.2 Power System for Powering Electro-Optic and Electronic Transmission System: System Diagrams

Configuration



16.3 Power System for Powering Electro-Optic and Electronic Transmission System: Cost Estimate

(a) *Material and Installation*

	Unit Price $	Total Price $
- Incremental Cost of Copper Pair 13km @	.14/metre	1,820.
- Installed Cost of 48V Power Plant at Control Centre		5,000.
Total Material Cost of Configuration Shown		$6,820.

TOTAL SYSTEM COST FOR STAGE I, 26km SYSTEM

- Power on Both Sides of Highway	$12,280.
- Power on One Side of Highway	$ 8,640.

Estimated Cost of Material and Installation per metre of Highway:

Both Sides of Highway	$	0.47
One Side of Highway	$	0.33

17.0 LINE COMMUNICATION SYSTEM, SUPPORT STRUCTURE AND FIBER AND COPPER CABLE INSTALLATION

17.1 Description:

Two alternative configurations for the installation of the line communication system, support structure and fiber cable are discussed here. The first (option I) refers to installation on both sides of the highway, as discussed for the coaxial cable system described in Volume 5 of the Highway 401 Corridor Study.

However, we have also looked at installation on one side of the highway (option II) because such installation is perfectly acceptable with fiber cable. Fiber cable has (a) a life expectancy of 30 years or more, (b) it is immune to lightning strikes, (c) the variation in the quality of its transmission is insignificant and (d) because of its lower attenuation characteristic, it requires less electronics which are prone to failure. Moreover, in the event that there is a break in the cable, say from the collapse of a bridge caused by earthquake or other major catastrophe, a fiber restoration link can be placed on the surface of the roadside for the damaged section. This can be done quickly because the fiber is small, flexible and strong. This approach is not practical in the case of coaxial cable due to its rigidity and size.

The configuration on one side of the highway provides for limited crossovers to allow for the location of cameras and changeable message signs on both sides of the highway. In the case of traffic detectors, installation on both sides of the highway for the placement of the detectors, and collecting signals on both sides. The only difference in the case of installation on one side of the highway is that an additional small channel would have to be cut through the highway median to allow for all the conductors bearing signals to terminate on one side of the highway. These conductors would be connected to 19 gauge copper cable which serve as a means of bringing together the signals from within the highway zones discussed in the description of the data system. This would make the

electronic subsystems more concentrated and hence easier to service and maintain.

The estimated costs per metre of highway are $24.54 for installation on both sides of the highway, and $16.23 for installation on one side of the highway.

17.2 Line Communication System, Support Structure and Fiber and Copper Cable Installation: Cost Estimate

In order to arrive at cost estimates, three field visits were made to the 26km part of Highway 401 which constitutes stage I of the project. The MTC maps of the highway were also examined and discussions were held with traffic and engineering staff at MTC. The visits and discussions provided a basis for deriving the estimated distances for the different installation methods and support structure required. It should be emphasized that these estimates are only for planning purposes and more accurate data will need to be collected for system design purposes.

Recent experience and available data suggest that the costs of installation and support structure are as follows:

			$/Metre
a)	Trenching, including simultaneous placement for fiber and copper cables, 30" or more below ground		6
b)	Under highway conduit		
	- Special steel pipe	21	
	- Pipe placement	17	
	- Pulling Fiber Cable	2	40
c)	Overpass and elevated highway (attached conduit)		
	- Some PVC and some steel conduit	9	
	- Fiber and copper cables placement	2	
	- Conduit placement	7	18

(i) Estimated Cost, Option I: Both Sides of Highway

	Trenching	Under Highway Conduit	Overpass and Elevated Highway
Distance (km)	35	2.6	18
Cost ($)	210,000	104,000	324,000

TOTAL COST FOR STAGE I ..... $638,000.

COST PER METRE OF HIGHWAY ..... $ 24.54

(ii) Estimated Cost, Option II: One Side of Highway

	Trenching	Under Highway Conduit	Overpass and Elevated Highwa
Distance (km)	23	1.7	12
Cost ($)	138,000	68,000	216,000

TOTAL COST FOR STAGE I ..... $422,000.

COST PER METRE OF HIGHWAY ..... $ 16.23

18.0 COMPARISON OF ALTERNATIVES

The estimated total costsper metre of highway for the various subsystems are shown in Table 18.1 for installation on one side and on both sides of the highway. The cost of the subsystems which are essential for any of the video and data options is $16.90 for installation on one side of the highway and $25.73 for installation on both sides of the highway. For the two data systems considered, the variation in the cost is not very significant in terms of the cost of the overall project. Because of the technical superiority of fiber, we would recommend that it should be used for this system.

The costs of the four video systems are examined in detail and range from a low of $16.02 for the switched baseband system installed on both sides of the highway to a high of $27.14 for the digital system installed on one side of the highway. It should also be noted that from a technical point of view the first three video systems provide equal access to all signals. However, the digital system, although configured in an optimal way to provide reasonable costs, has a severe drawback in terms of limited access to all cameras since only one camera signal in three on a given fiber can be monitored at a particular time.

The total costs of the various options (4 video, 2 data, installation on one or both sides of the highway) are shown in Table 18.2. These show that for all options installation on one side of the highway is significantly cheaper than installation on both sides of the highway. In addition, the switched baseband and F.M. multiplex systems will cost signficantly less than the other two systems.

Table 18.1

Estimated Total Cost ($) Per Metre of Highway by Subsystem, for One Side and for Both Sides of the Highway

Subsystem	One Side of Highway	Both Sides of Highway
Common		
Support Structure and Installation of Cable Lines	16.23	24.54
Power	.33	.47
Voice	.44	.72
Subtotal	16.90	25.73
Alternatives		
Data		
1. Copper	8.62	8.62
2. Fiber	8.59	11.00
Video (Fiber)		
1. Baseband	25.51	26.11
2. Switched Baseband	17.44	16.02
3. F.M. Multiplex	17.76	17.91
4. Digital	27.14	26.90

Table 18.2

Estimated Total Cost*($) Per Metre of Highway for Various Options and for One and Both Sides of the Highway

Options		One Side of Highway	Both Sides of Highway
Video (Fiber)	Data		
1. Baseband	Copper	51.13	60.46
	Fiber	51.10	62.84
2. Switched Baseband	Copper	43.06	50.37
	Fiber	43.03	52.75
3. F.M. Multiplex	Copper	43.38	52.26
	Fiber	43.35	54.64
4. Ditital	Copper	52.76	61.25
	Fiber	52.73	63.63

* Each option includes the cost of the common subsystems, i.e. support structure and installation of cable lines, power and voice.

19.0 COAXIAL CABLE VS FIBER

In order to compare the costs of the system using coaxial cable with those of fiber cable, we have extracted the relevant information from Volume 5 of the Highway 401 Corridor Traffic Systems Management Study of MTC, and normalized this on a per metre of highway basis. This provides a total cost of $77.01 per metre of highway for a coaxial cable system. Since this figure refers to installation on both sides of the highway, we have only used our estimates for both sides of the highway for comparison purposes, (see table 19.1).

The figures show that the costs of the switched baseband and F.M. multiplex systems are significantly lower than that of the coaxial system, for both material and labour. This is because the former use less electronics, and the fiber cable can be installed more easily and quickly because of its physical characteristics.

The total cost of the switched baseband system is $52.76 while that of the F.M. multiplex system is $54.64 per metre of highway and these are roughly 30 per cent cheaper that the coaxial system. It should be noted that the costs of the system can be further reduced by installation on one side of the highway. In this case the switched baseband system costs $42.93 per metre of highway while the F.M. multiplex system costs $43.25 per metre of highway. These figures are approximately 45 per cent lower than the cost of the coaxial system.

We, therefore, recommend that either the switched baseband system or the F.M. multiplex system, installed on one side of the highway, should be chosen for this project.

Fiber prices are likely to continue in the downward direction. The profit margin is high and supply can be increased rapidly. The recent price trend is shown in the graph below.

It should also be noted that coaxial cables are no longer being manufactured in Canada.

Table 19.1

Comparison of Estimated Costs ($) of Coaxial Cable System* and Fiber Systems, Per Metre of Highway

System-Video and Data	Material	Labour
Coaxial Cable	43.32	33.69
Fiber Systems:		
1. Baseband	42.43	20.42
2. Switched Baseband	32.46	20.30
3. F.M. Multiplex	34.26	20.38
4. Digital	42.14	21.50

* The figures for the coaxial cable system are derived from Volume 5 of the Highway 401 Corridor Traffic Systems Management Study of MTC, page 21 (item 4) and page 23 (item 8). The figures have been normalized to give a per metre of highway cost. Note that the estimates for the coaxial cable system refer to 1979 and no allowance has been made for inflation. The estimates for the fiber systems refer to 1981.

Description of Estimated Costs per Metre of Highway for Coaxial System

1) Data Communication System (p. 21,Vol 5, and p. 2, Terms of Reference)

a) Material required for 250 detector and ramp metering stations and changeable message signs $276,000

Material required for Stage I (26 km):

$\frac{137}{250}$ x $276,000 151,248

Cost per meter of highway for Stage I:

$\frac{\$151,248}{26,000}$ 5.82

b) Labour for 250 stations and signs 175,000

Labour for Stage I (26 km):

$\frac{137}{250}$ x 175,000 95,900

Cost per meter of highway for Stage I:

$\frac{\$95,900}{26,000}$ 3.69

2) Broadband Cable Communication Network Subsystem (p. 23, Vol.5)

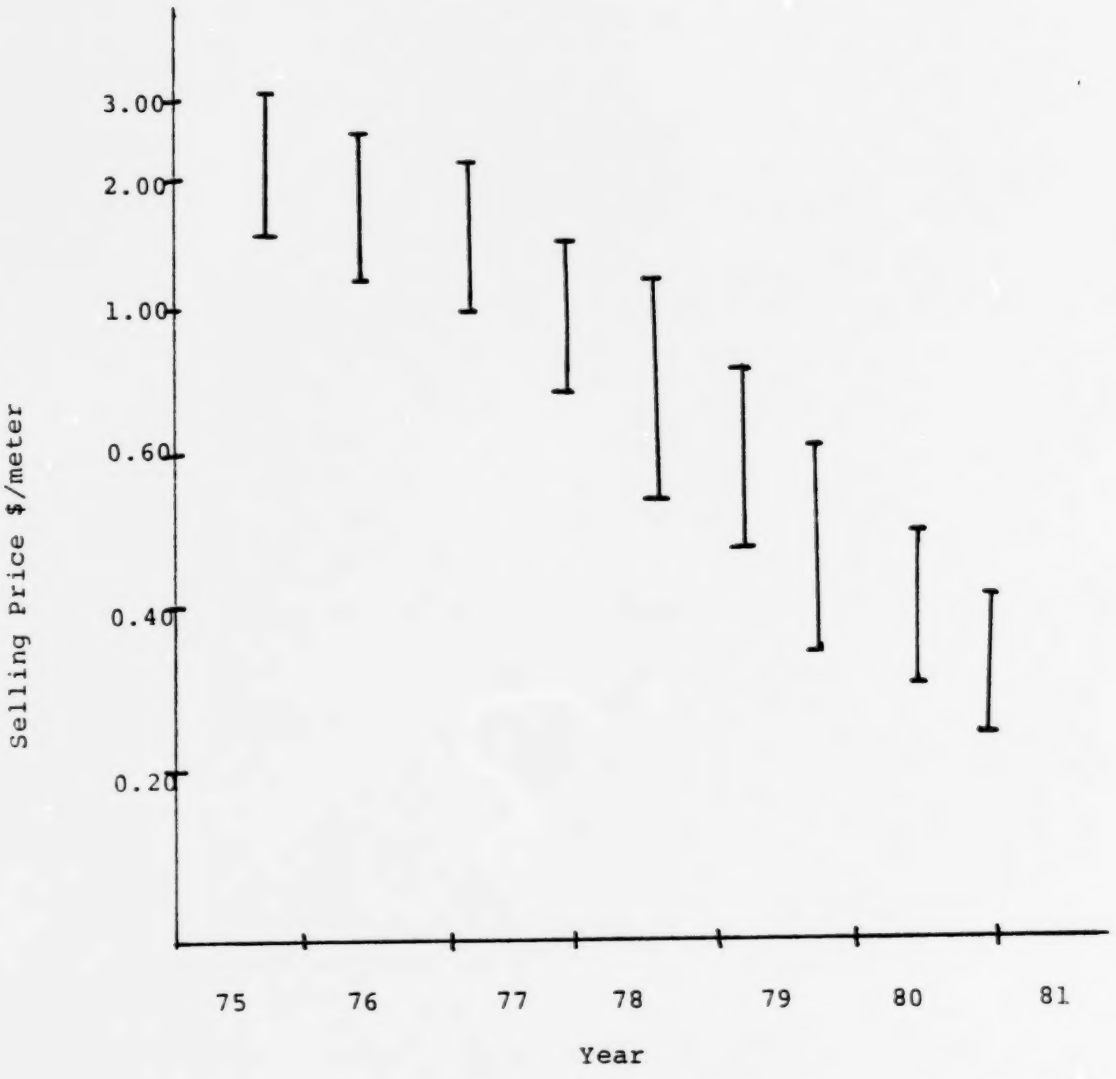
a) Material Cost per meter of cable..... $18.75
Material Cost per meter of highway..... 37.50

b) Labour Cost per meter of cable..... 15.00
Labour cost per meter of highway..... 30.00

3) Total Cost of Material per Meter of Highway..... $43.32

Total Cost of Labour per Meter of Highway..... $33.69

OPTICAL FIBER PRICE TREND



Ref: Corning
Based on information
Published in IFOC

20.0 EXTENSION OF THE SYSTEM

The fundamental systems developed for Stage I provide for easy extension to Stage II using long wavelength optical technology and the cable already installed in Stage I. Because of the later planned starting date for Stage II, it is expected that the unit costs for Stage II will be lower than those for Stage I. However, the configuration developed for Stage I will be directly applicable to Stage II.

The extension of the Stage I configuration to incorporate a control centre for the Ontario Provincial Police located across Highway 401 from MTC, can readily be accommodated by taking a lateral transmission system from the MTC control centre. The details of the configuration should be considered during the design phase of the program.

The interconnection of the data system for use by the Toronto Transit Commission control centre, should be made at the closest access point.

The possible future extension of the system in Stage III to include Highways 427, 409, QEW, Gardner Expressway, the Don Valley Parkway and the proposed Highway 403, (and, for that matter, any other highway in Ontario) can easily be carried out using the same configurations developed here. In addition, because of the modular nature of the configurations, it would be quite practical to separate the data system from the video system and apply the systems to meet the particular needs of the specific highway. This would result in substantial cost reductions.

We suggest that the Metro Toronto Traffic Control Centre be interconnected to the proposed fiber data system at the intersection of Yonge and Highway 401. This can be done with a copper or fiber system depending on traffic growth.

The proposed fiber will have lower attenuation in the second window or at longer wavelengths 1,300 to 1,350 nm. The attenuation of these wavelengths should be of the order of 0.9 dB to 1.3 dB/km. This very low loss is ideal for transmission of signals from Stage II and

also other highways in the Toronto area. However, at this stage the longer wavelength lasers are only gradually being introduced to the market and are still somewhat new and innovative. They are also more costly than the devices working in the 830 - 850 nm.

21.0 IMPLEMENTATION OF THE SYSTEM

The integration of the subsystem discussed in Sections 11 through 16 is shown in the diagram 21.1. This shows the hybrid proposed network architecture, which consists of a 6 fiber cable (4 video low attenuation fibers and 2 data medium attenuation) for video and data; copper cable consisting of 11 pairs for the purpose of provisioning of voice (increased reliability) and also for local zone data pickup (0.4km radius). This configuration has the advantage of equipment concentration reducing initial installation costs as well as reducing ongoing maintenance costs.

We estimate that, using a conservative time scheduling for the different activities, a fiber system can be installed and operating twenty months after a decision is made to proceed with it. However, if there were a pressing need to do so, the system could probably be installed and operating in twelve months. This can be done without any sacrifice in quality of material and services received from suppliers.

The implementation plan listing the required activities and time schedule are shown in the figure below. We have also identified the major milestones in the project, and these are shown in the figure.

The proposed system configurations recommended are for either FM or switched broadband.

In the case of FM, the precise interaction of lasers operating through combiners needs to be characterized as to isolation required from laser to laser. The second characterization required is that of three light signals being detected by a PIN-Diode to determine the cross modulation characteristics of the light detector.

In the case of the switched baseband, the baseband optical switch needs to be assembled and tested to determine the switching and precise attenuation characteristics.

However, the precise characterization of the above systems will be an important input to the system design and will assist in the design of a more cost effective system. ATS would be prepared to define these verification trials, arrange for these measurements to be undertaken and conduct the necessary work if MTC decides to pursue the fiber communication system for this project. The organization and conduct of these tests should not exceed eight weeks. The cost should not exceed $25,000, but it will depend to a large extent on the availability and cost of test equipment. The estimate given applies only if ATS conducts these tests.

21.1 Proposed System Integration

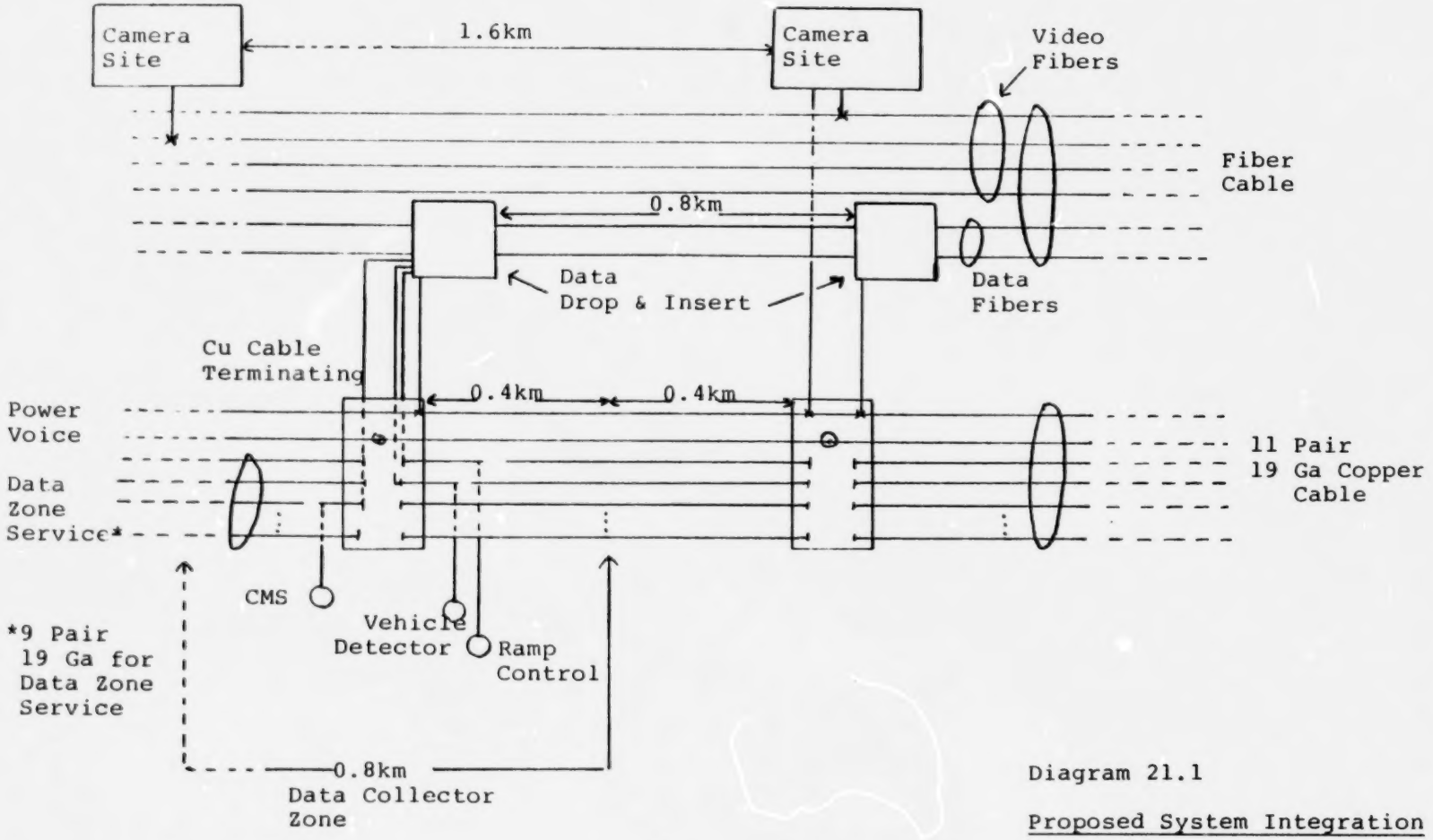
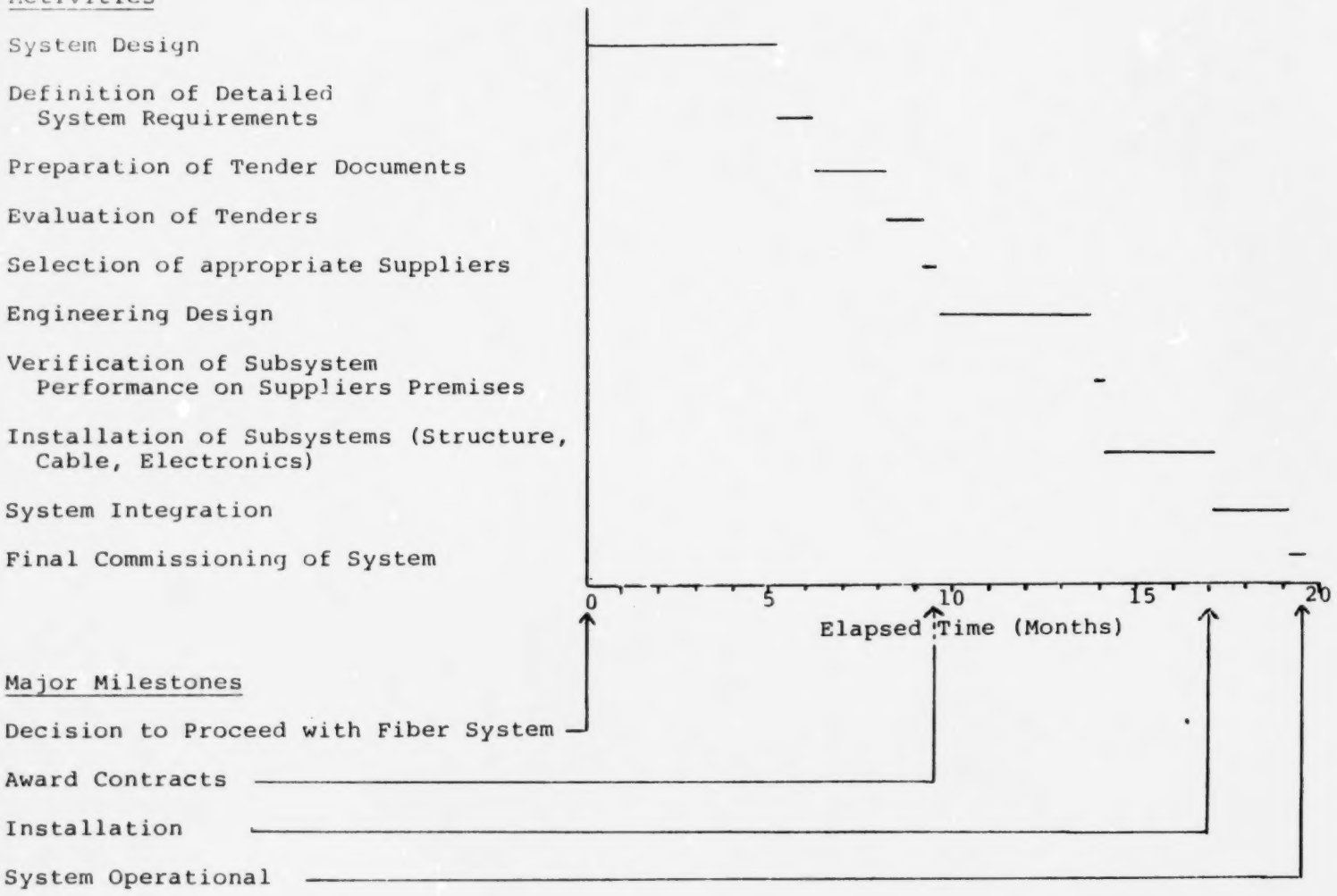


Diagram 21.1

Proposed System Integration

Implementation Plan and Schedule



22.0 Risk and Reliability

22.1 General

The reliability of fiber systems is expected to be at least as good as that of coaxial cable systems. The basic components used in the system, other than the laser, have proven field lives similar to equivalent coax cable components. Further, the fiber systems require fewer and simpler components. The proposed fiber systems require only two video repeater locations, compared with approximately 14 for coax implementation. The fiber repeaters do not require amplitude equalization for temperature changes, which is required for coax.

The reliability of lasers continues to improve. Life expectancies are now in the order of 15 years (120,000 hours). Failures are predictable, and hence preventable by routine maintenance.

Fiber systems are not subject to failure due to lightning, and are not affected by water leakage, or RF interference. Further, fiber cable is quicker

and easier to place, and is less subject to damage at installation or during its service life. The type of fiber (graded index) has gained wide acceptance in the industry and its life expectancy will meet all MTC anticipated requirements over 30 years as compared to 20 years for coaxial cables.

The proposed fiber based data system makes use of Light Emitting Diodes which have a life expectancy of 320,000 hours and T1 type electronics which have been in use in the telephone network for trunking purposes and also for rural communications for many years. The system has been cost reduced very effectively due to a large demand and the reliability of these systems is outstanding. The capacity of this system exceeds the current MTC service requirement but it will provide for future services for both high speed data and voice when required. The cost of this system is less than smaller capacity systems that were considered for this application primarily due to significantly reduced market demand which means added expense of semi-customizing.

The predominant demand for coaxial cable technology has been from CATV companies in which the main interest is the provision of entertainment services to the residential market. As such the emphasis has been to a large extent on low cost rather than reliability. The fiber technology developments on the other hand have been driven by industries that depend on highly reliable communications such as telephony, power utilities and the military. Some examples of large currently planned systems are the Saskatchewan fiber system over 3,000km in length for their portion of the Trans-Canada communication systems as well as a video, voice and data system which interconnects some 150 towns in that Province. Manitoba is currently placing a comprehensive fiber network to interconnect a number of telephone exchanges in Winnipeg. Similar systems have been installed in Bell Canada Territory, British Columbia and Alberta. In the United States, the A. T. & T. System is placing fiber systems for the Boston-Washington corridor communications among other applications such as a recently announced plan to place a fiber trans-Atlantic communications system.

The main reasons why fiber systems are attractive for these applications are expected reliability cost effectiveness, and long life expectancy.

The experience to data with fiber systems has been excellent (see articles included in Appendix). The installation costs have been lower than conventional systems due to small size and greater flexibility of fiber cable as well as fewer splices needed and reduces requirement for electronics due to low loss characteristics of the fiber cable.

Quantitative data on the reliability of local networks is not available for copper and coaxial systems and certainly not for fiber network. This type of information is kept for long haul communications on microwave systems. However, we suggest that MTC make a spot check on experience in both installation and maintenance with the following organizations which have experience with fiber optics.

1. Yorkville - Bell Canada
   (Video, data and voice)
2. Montreal - Bell Canada
   (1.544 Mb/sec p.c.m. trunk)

3. Vancouver - B.C. Telephone Co.
   (1.544 Mb/sec p.c.m. trunk)
4. Ottawa - D.N.D., H.Q.
   (T.V. and data)
5. Ottawa - Ministry of Transport
   (Data)

22.2 Technical Considerations

Given that the MTC requirement is unique, and this feasibility study is constrained to paper, the proposed fiber systems configured by ATS for this application are unique but consist of building blocks or subsystems that are available within the time frame of the MTC requirement. In pursuance of good engineering practice, we recommend that a laboratory verification and initial characterization of some technical parameters be undertaken before the design stage of the project is initiated. The purpose of this verification phase is twofold:

1. To determine technical characteristics;
2. To obtain technical characteristics which will be an input to the system design and optimization.

We estimate that the cost of such verification should be within $40K to 60K.

This step will reduce technical risks and help to keep the cost of the final system down, as this information would be made available to the system designers giving them the detailed limitations. To reduce risk and improve reliability of the electro-optic and electronic devices, we recommend that all these subsystems are put through an accelerated proof in heat test before they leave the factory and in addition suppliers are asked to guarantee their performance for a period of 3 to 6 months after they are installed.

The fiber cable installation should be handled by the cable supplier and their chosen contractor, and the supplier be contractually committed to MTC on the installed performance of the cable. The above recommendations will signficantly reduce the MTC risks of the system working to the set design standards.

The main maintenance problem of any cable system is the damaging of cables during construction that may take place in the vicinity of the system in the future. This problem can be partially avoided by placement of above ground markers with warning signs indicating the presence of the underground

cable and physical protection at hazardous locations. In spite of this practice, cables are cut on occasion and corrective action by maintenance people has to be taken. The normal procedure with standard coaxial or telephone installations is to send a repair person to repair the cut by splicing the cables. This procedure is usually time-consuming and costly. In the case of coax or telephone cable, this is the only option available. With fiber systems this practice still applies. However, a second option is to restore the given link on a temporary basis with the aid of surface cable which can be accomplished quickly and effectively due to the small size and strength of the cable.

The second most significant problem with operating coaxial cable systems is moisture seepage which causes initially partial transmission impairment leading to disintegration of the cable portion affected causing a catastrophic failure. At this time there is no evidence that this problem exists with fiber cables. Hence, experience suggests that fiber cables are immune to moisture effecting problems. The frequently used solution to this coaxial cable problem is to pressurize the cable.

The pressurization support system needs ongoing maintenance which is an added cost which would not be incurred with fiber cables.

The third problem with coaxial cable systems is the handling of the coax at the various repeater or junction points which often cause problems of cable kinking, which in turn introduces cable discontinuities and transmission degradation. If cable connectors are not properly tightened there is a tendancy for foreign signals such as broadcast and other signals to enter the system thus causing interference. These problems are eliminated with fiber systems.

The cable kinking problem can be caused by ice forming on the cable sheath. The best form of protection against this happening is by installing the cable below the frost line and by making use of conduit at junction points. However, this problem affects both coaxial and fiber cables and with fiber if it does happen it will increase attenuation by some 2dB and the appropriate attenuation margins have been used in the system design so as not to cause failures in most situations.

22.3 Maintainability

In the event of fiber system failure, it is proposed that MTC carry an inventory of spare parts that normally would amount to 7% to 10% of the total system which would be used to replace the failed components. Further it is suggested that MTC make arrangements with suppliers to repair and overhaul the defective parts. The turn around norm in the industry is 2 to 4 weeks for repair service.

The staff operating the system from the traffic control centre could provide the expertize required to maintain the system if they undergo training during the installation period. The other alternative is to subcontract both routines and emergency maintenance to a Toronto firm. The diagnostic and maintenance procedures must be provided by suppliers on a subsystem basis together with the hardware.

We estimate that the cost of normal preventive maintenance on the fiber communication system should not exceed $100,000 p.a. However, a much more accurate estimate should be made during the system design phase which would include the thorough examina-

tion of maintenance procedures and practices.

22.4 System Expandability

The fiber system configurations developed rely on a two window fiber cable. It is proposed that the lower window be used for the video capacity requirement of Stage I utilizing short wavelengths (800 nm to 850 nm), the fiber attenuation characteristics are 3 to 4 dB per km. The second fiber window occurring in the 1300 nm 1350 nm with an expected 0.9 dB to 1.3 dB/km loss should be reserved for the addition of Stage II. Thus, no additional fibers will be required for Stage II extension of the Stage I system except that the repeaters used in Stage I will have to be upgraded to include long wavelength amplification.

The data system proposed for Stage I has more than adequate capacity to handle additional data arising from Stage II without any additions to Stage I fiber system.

Both video and data systems described are suitable

for applications to other proposed highway locations in the Toronto area and they are recommended in the Implementation Plan on the assumption that MTC follows the course of action recommended by ATS to reduce risk.

Reference to Glossary of Terms

Terms of reference pertaining to fiber optic terminology used are according to "Optical Waveguide Communications glossary No. SP79-4". NTIA, U. S. Dept. of Commerce.

APPENDIX: SELECTED PUBLISHED ARTICLES ON FIBER APPLICATIONS

Installation Experience with Optical Fiber Cable

Although fiber optic cable has unique characteristics, installation techniques differ little from equivalent installations of conventional cables.

By G. H. Foot and J. B. Masterson,
General Cable Company

This paper includes an account of the field experiences with early installations of optical-fiber cables undertaken by General Cable Company in 1976-77, including the first optical cable to be placed in public telephone service, followed by a description of modern optical cables, their mechanical performance and the account of a recent installation (1980) of an optical cable in a very congested and difficult location in central Manhattan, New York.

There have been numerous publications on the design concepts and the engineering performance of optical-fiber cable systems for use in speech, data or video transmission. The rate of development and improvement of these systems continues to be rapid and has been well documented. Less has been published concerning experience obtained in the installation of optical cables, although this is a subject of integral importance to the provision of working optical systems.

General Cable Company, a division of GK Technologies, Incorporated established the policy of designing and producing optical cables which would require no special care in field installations beyond that normally given to conventional cables. Further, it was determined that these optical cables should be amenable to the same handling practices as conventional cables and be suited to installation by regular craft crews employing commercially available installation equipment.

These criteria were met with complete success in a pioneering series of optical cable installations in 1976-77. These installations were quite advanced for that period and all involved functioning operational systems (as contrasted with experimental installations) and included the world's first optical fiber cable for lightwave transmission of regular public telephone traffic.

These early installations presented numerous difficulties due to terrain and existing facilities. One cable laid in trenches was successfully threaded in 1 Km. lengths under eighty crossings of other utilities including railroad tracks, power cables, steam mains, water pipes, roads and similar impediments in an area very congested with existing plant. Another cable drawn into ducts in 1 Km. lengths required only those precautions which would have been taken with conventional cables except for the provision of a method of measuring the tension in the winch line and an automatic cut-out if the tension were exceeded.

Optical fiber cable installations require minimal divergence from the standard practices applicable to conventional cable installations. This success has opened the way to the employment of optical fiber cables on a large scale within communications cable networks. In fact, it is not unusual to be asked to install cables of various types, conventional and optical, in the same trench or in the same duct during a single operation as a measure of economy and this mixed working presents no difficulty at all.

Cable design

Optical fibers are small in diameter (125 μm) and, in consequence, will withstand only a small load. They are also subject to a phenomenon known as microbending in which the effect of a very large number of imperceptibly small bends can destroy the transmission performance of the fiber. The cable must withstand the mechanical stresses to which it is subject during installation and during its lifetime but the fibers must be effectively isolated from those stresses. As is well known, bare glass fibers are adversely affected by high humidity and cracks can develop if protection is not afforded to the fiber when it is manufactured. The extremes of cable temperature must not cause excessive variations of fiber attenuation and prolonged temperature cycling of the cable must not cause the nominal cable attenuation to depart from its original value. To counter these effects the fiber is effectively 'buffered' by a soft and then a hard plastic coating and is further 'cushioned' within a suitable cable design into which a separate strength member is introduced so that the fiber is protected from the cable stress.

The General Cable design of optical-fiber cable employs double-buffered fibers which are individually colored in one of twelve distinctive colors making for

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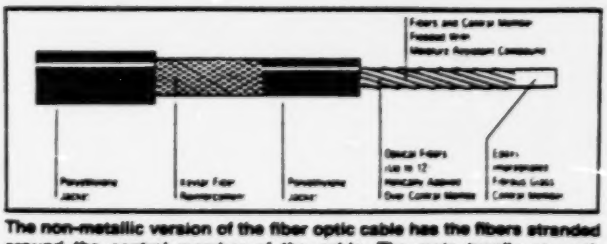


The non-metallic version of the fiber optic cable has the fibers stranded around the central member of the cable. The main tensile strength member is applied between the two polyethylene jackets.

Abstracted from a paper presented at the Second U.S./Southeast Asia Telecommunications Conference, Singapore, December 3, 4, and 5, 1980.

easy recognition during splicing. Any number of fibers up to twelve are stranded around a semi-flexible epoxy-resin impregnated fibrous glass rod which forms the central member of the cable. This central rod has the same thermal behavior as the fibers themselves. It also has the useful property of preventing the cable from being bent with an excessively small radius which could result in damage and in this manner greatly improves the handling properties of the cable.

At this stage, the cable is filled with the same type of filling compound as is employed in conventional filled cables and which provides a barrier to the penetration of moisture.

A twin-sheath of black polyethylene is then added and between the two sheaths the main tensile strength member of the cable is formed by contra-rotating strands of kevlar, a material with a strength greater than steel, weight-for-weight.

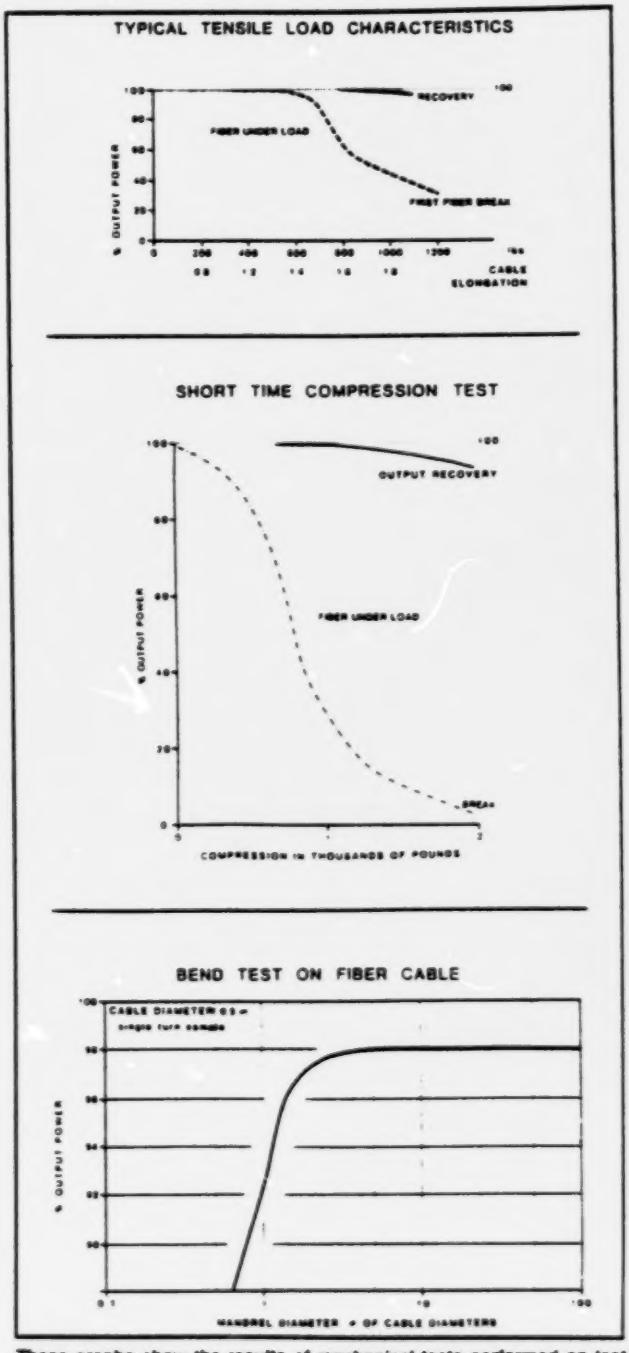
This completes the cable in its non-metallic version. A cable finished in this manner is suitable for installation in most situations and particularly, of course, in locations where a completely non-metallic construction has been specified because of the presence of high electrical voltages, the fear of lightning damage or for any other reason.

For many applications a greater mechanical strength will be desired in the optical cable and for this reason a range of metallic outer coverings have been made available, any one of which can be added to the basic non-metallic structure described above.

- A tube may be formed over the basic cable from a flat aluminum strip and hermetically sealed with a longitudinal helium arc weld. Over the aluminum is flooded an asphaltic anti-corrosion material, and over that is extruded a black polyethylene jacket. This cable has considerable additional tensile strength and is also resistant to crushing forces. In effect, it incorporates a miniature duct, inasmuch as the aluminum tube serves this purpose and also affords complete protection from the penetration of moisture or water vapor. An additional advantage of the aluminum tube is that it enables the cable to be pressurized, if desired.
- In a second design, a closely fitting thin aluminum tape is folded with an overlap directly over the cable. This aluminum tape is coated on both sides with a co-polymer of polyethylene and the application of heat during manufacturing seals the overlap. The mechanical protection of this cable is less than the previous one, but is entirely adequate for many applications in which a more economical cable is desired. It is not, however, designed for static pressurization.
- Where precautions against attack by rodents are necessary, e.g. gophers in the continental USA, or where exceptional mechanical strength is required, an additional corrugated steel tape protected with anti-corrosion compounds is folded with an overlap over the aluminum tube cable and a further polyethylene jacket is extruded overall.
- A cable suitable for aerial suspension is available. This is self-supporting because of the inclusion of a steel messenger strand.
- Cables with more than 12 fibers and with the inclusion of copper conductors for power feeding are also available.

A satisfactory mechanical performance is essential if an optical cable is to withstand the stresses of installation and is to have a long and useful life.

Before the fibers are incorporated into the cable, samples are tested under humidity and temperature conditions which accelerate the aging which may be experienced during their lifetime. The strength of sample short gage lengths of fiber is measured in its natural state, after exposure to 100% humidity, and after preload and static fatigue tests. The data are analyzed and the maximum permissible fiber load is computed to provide the design life expectancy. The correct cable design ensures that the fibers are not subjected to a load exceeding this maximum during cable fabrication or installation.



These graphs show the results of mechanical tests performed on test samples of finished optical cable. These tests are for Type FPA construction, which includes an overlapped aluminum tape over the outer polyethylene jacket, followed by yet another polyethylene jacket.

Several mechanical tests are performed on test samples of finished optical cable, including tensile, compression and bending tests. During these mechanical tests the fibers are illuminated at 0.85 μm and the output light is monitored continuously. The cable withstands very large load and the severe distortion during these tests and the transmission properties of the cable recover when the loading is removed. Very adequate margins of safety are provided beyond the recommended limits for stresses during installation.

Cable installation

The similarity between optical and conventional cables in respect to treatment during installation has been stressed, but there are also important differences. Of these differences the most significant is the requirement to handle optical cable in long continuous lengths. It has been convenient to standardize on a length of 1 Km, although any other long length would be equally valid from an engineering viewpoint.

The need for installation in long lengths is to minimize attenuation loss which occurs when optical fibers are spliced, relative to the very low attenuation losses which the fibers themselves demonstrate. Short lengths and additional splices are to be avoided in optical-fiber cable installations. Fortunately, optical cable is small in size and light in weight and can be manufactured in long lengths without inconvenience; it is admirably suited for installation in much longer lengths than could be contemplated with conventional cables.

There are considerable economies to be realized in installing optical cables in long lengths in a single operation. Further economies result because the expense of frequent splicing is avoided. Moreover, the reliability of the cable is improved because the number of splices is small. In many circumstances in duct installations, a major saving can result from the use of optical cables in occupied ducts, which could, in some cases, avert the construction of new ducts. These facts are all very positive advantages for the use of optical cables; when coupled with the fact that the low attenuation of optical cables frequently makes it unnecessary to employ intermediate repeaters or regenerators or to provide power at locations intermediate between the terminal stations, the case for the choice of an optical cable system is most convincing.

Experience in the handling of long lengths of optical cable is of prime interest and importance. We shall take as our illustration, the recently completed installation by General Cable in conjunction with the customer, Manhattan Cable TV, of a 5.2 Km optical cable system for video transmission in New York City between East 23rd Street and the Gulf and Western Building at Columbus Circle on West 59th Street. (See "The Sidewalks of New York," *TE&M* Sept. 1, 1980).

The duct system in Manhattan is enormous in extent with manholes of all sizes, but it is crowded with cables of every description and age such that space for a new cable or space for an additional splice is difficult to find. There are hazards of water, heat, steam and potentially dangerous gases. The dense street traffic makes it necessary to work primarily at night and to withdraw all surface equipment each day.

From a maintenance standpoint, re-entry into a manhole is difficult. It was therefore most attractive that the optical system would require no intermediate repeaters and that the cable could be laid in six lengths with only five field splices even though it would pass through 44 manholes along the route.

The Manhattan duct system is intended for conventional cables and will not permit an individual cable pull of more than 600 feet at the most. Moreover, there are acute changes of direction between ducts in and out of manholes and considerable changes of level. A further complication was the requirement to pull six cables into the chosen duct, five of which were semi-rigid coaxial cables.

In several locations, the optical cable was placed by pulling it into an aluminum tube (flooded with an anti-corrosion compound and sheathed with a polyethylene jacket) which had been pulled into the duct with the five coaxial cables mentioned above. This tube, pre-lubricated with a compound compatible with polyethylene, served as a conduit or "mini-duct" through which the optical cable could be subsequently pulled and pass through several manholes in one continuous length. In those locations in which the mini-duct became impassable, it was removed and the fiber optic cable placed directly into the duct.

After the optical cable had been dressed into position in an intermediate manhole, a flexible steel tube, previously threaded over the cable and mini-duct, was pulled back into the manhole so that it completely covered and protected the optical cable within the manhole and was then sealed to the mini-duct. The same type of flexible steel tubing was also used as a guide to lead the optical cable through a manhole and to span the differences of direction and level.

Continued on next page

Cable coiled in manhole in temporary storage for the next night's pull.

In some cases, the cable installation was facilitated by pulling in both directions from the mid-point of a cable length; this required one half of the cable length to be removed from the reel and to be coiled on the ground. In other cases, in which completion of an operation was not possible by the morning, it was necessary to coil the cable temporarily into a manhole and to remove it for the completion of the work the next night. It is noteworthy that the cable withstood all this additional handling without creating any problems or suffering in performance.

At the terminal stations the optical cable is threaded into the buildings for a considerable distance and is led in one continuous length to the floor on which the transmission equipment is situated so that a splice is not required immediately outside the building. This is our standard practice and the operation has always been performed without difficulty.

Splicing and testing

General Cable has pioneered the splicing of optical fibers by fusing; that is by aligning two fibers end-to-end very accurately and then joining them permanently by melting the two ends so that they fuse together. This method, which results in a stable splice of low attenuation (0.2dB or less) is becoming the prevalent technique and is generally accepted to be superior to a splice made mechanically.

The alignment is made under a microscope by means of micrometer adjustments in two places. The fusion is effected by means of an electric arc between two small pointed electrodes on either side of the splice.

The use of open flame or devices producing electric arcs capable of causing the ignition of the gases which may be present in a manhole is prohibited in New York and in many other locations. General Cable has developed apparatus for fused splicing which can be operated safely within a manhole or in other places which may contain hazardous gases or which may be flooded.

Briefly, the fusion is performed within a clear plexiglass chamber which can be sealed and purged and pressurized with clean air to maintain it free of undesirable gases. The power leads and air supply are taken to the splicing chamber from outside the manhole within a flexible hose which is itself pressurized. A pressure switch, indicator and other safety features are provided and a sensor shuts off power in case of loss of air pressure. A float chamber mounted at a suitable level detects any rise of water and also disconnects power if necessary.

Cable is removed from the reel and deployed on the street to facilitate pulling in both directions from the mid-point of the length.

The availability of a splice case and accessories is an essential adjunct to successful splicing under field conditions. This splice case can be physically attached to the fused splicer during the splicing operation so that convenient working conditions can be maintained and hazards to the movement of delicate fibers can be eliminated.

A feature of the splice case is the inclusion of an 'organizer' which incorporates a number of precisely spaced grooves to hold fibers in position and with larger grooves to hold completed splices in a straight position and in a secure manner. Sufficient spare fiber is available within the splice case to enable any future repairs or alterations to be made.

Fused splices are made individually and the coating used originally during manufacture of the fiber is replaced. The splices are then covered with a plastic tube which is heat shrunk at both ends to enclose the splice. Each splice is then placed in its permanent position in the organizer.

The closing of the splice case completes the operation which will occupy about two hours in setting up the equipment and a further three hours for all stages of splicing, closing the case and removing the equipment.

Testing of both attenuation and bandwidth can now be made in the field; these measurements, in conjunction with the complete information furnished with every reel of cable, enable the installation of cable and the splicing of cable to be monitored closely as the work proceeds.

It is particularly important that the condition of every length be verified and that the quality of every splice be determined as the installation progresses. Reliance placed on measuring the overall attenuation of a completed link will not reveal that one particular splice has excessive attenuation and it is then unlikely that the imperfect splice will be detected throughout the life of the system.

Another instrument in general use is the Optical Time Domain Reflectometer (ODTR) which is useful in measuring cable attenuation and will serve also in locating breaks in individual fibers if the cable has been damaged.

Conclusions

The installation of optical cables differs little from the equivalent installations of conventional cables with copper conductors, and the requirement to handle optical cables in long lengths presents no problems which cannot be solved with the equipment and the techniques which are now available.

Long lengths, small size and light weight are substantial advantages for optical cables and result in significant economies in installation.

The type of personnel required for the field installation of optical cables is no different from that employed in installing conventional cables; the additional training is easily given and is easily assimilated.

Saskatchewan Fiber Project Plows On

Work resumes this month on world's largest fiber optic system. Several innovations are being applied for the first time.

By Graham C. Bradley and Adolph C. Howorko
Saskatchewan Telecommunications

One of the warmest winters on record is allowing Saskatchewan Telecommunications to resume cable plowing this month for their C$56 million broadband network (BBN)—the longest fiber optic system in the world.

The 2000 mile BBN project, announced and begun last year, will provide a fiber highway throughout the sparsely populated Western Canadian province. Fewer than one million people live in this prairie province, which is almost the size of the state of Texas. (Texas has almost thirteen times the population of Saskatchewan.)

It was only March of 1980 that SASK TEL awarded Northern Telecom a C$22 million contract for the provision of the optical system, and within a few weeks, Northern Telecom announced that it would locate its Optical Systems Division in Saskatoon, Sashatchewan. Since then this first large-scale, long-haul, application of fiber optics has attracted attention not only from all over North America, but also from Europe, Australia and Japan.

The provincially-owned telephone company, which is commonly referred to as SASK TEL, opted for the integrated network because of a belief that the ideal delivery system in a democracy must give every person the equal right to communicate, both as a sender and a receiver of the messages. Equal rights to receive and send information means equal access to the delivery system—whether for voice, print, data, facsimile or video.

Before 1985 it is expected that the backbone network will have been installed and that the 51 largest communities will have been connected. Plans for the integration of both telephones and CATV are developing at a rate faster than expected. In fact, the last quarter of 1981 will see the first message-equipped cross section of the BBN. The BBN, once in place, will provide the long-haul facility to provide Saskatchewan communities with the four American networks in addition to the existing Canadian networks.

Needless to say, those involved with the project have frequently been asked why the telco chose fiber optics. For one thing, the system had to have the capability to originate cable TV from the smaller communities. The fact that it was going to be used bi-directionally for both CATV and also for telephony made a fiber optics network economically viable, since the capital works costs were shared: the cable, the armor plate, repeater housings, back-up battery systems and alarm networks.

A satellite up-link was too costly and the high cost of both the civil works and the required interconnection facility, for analog or digital radio made microwave out of the question. It should be noted that, in this midwestern grain-growing province, towns were established at ten mile intervals so farmers, or more specifically, their horses, did not have to haul grain too far. Co-ax was ruled out because it was not cost effective for providing telephone-grade service on long-haul systems.

The immunity to electrical interference was also an attraction since it meant that sites which were previously unusable could now be considered.

And so, SASK TEL chose fiber. Plans are already being considered for future expansion of the network to towns with fewer than 500 inhabitants and eventually to farms and individual households. And it is

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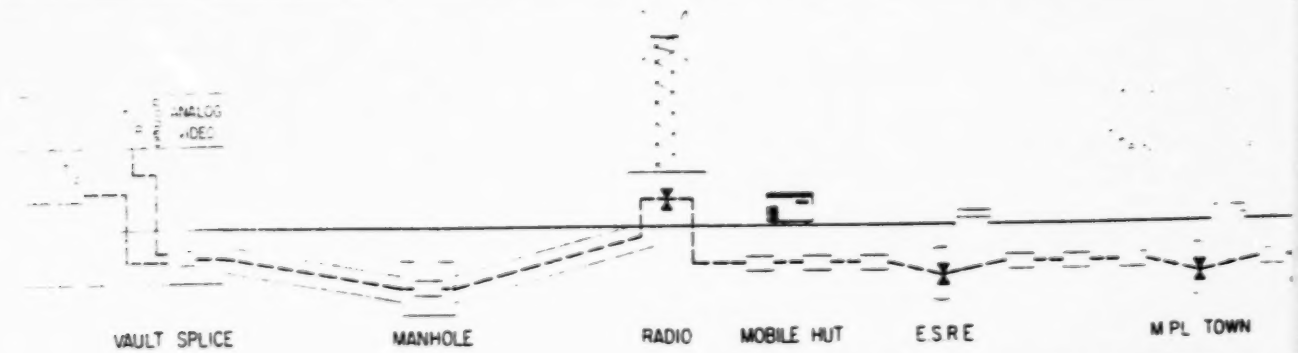
The SASK TEL long haul fiber optics transmission system is shown diagrammatically on this and the succeeding two pages.



expected that within the next few years, the initial capacity of the BBN system could be increased from three to five times, using new technology. As a digital, rather than analog, system, the network will be virtually free from noise distortion build-up, providing a near error-free medium for sending print and graphic material.

A project of this size, in a technology so new, demands constant innovation. Both SASK TEL, and Northern Telecom with its subsidiary Bell-Northern Research (BNR), are continually working on refinements necessitated by the application of this technology on such a large scale. Some of the SASK TEL innovations in support of size have included the 214-F diagram, Earth Sheltered Repeater Enclosures and ripple splicing.

The 214-F is a route optimization diagram, which provides a technique for selecting the most economically viable, field-mounted, repeater location.

Earth Sheltered Repeater Enclosures, commonly call ESREs or Root Cellars, were developed because of the need for a low-maintenance structure. Going underground was desirable because at 12 feet below the surface there is less than 10 degrees F temperature variation—an important factor in the provision of a comfortable working environment for personnel and equipment in a climate that can swing from −40 degrees F in winter, to 100 degrees F in summer.

Ripple splicing is a technique which assumes all visually inspected splices are acceptable, rather than the traditional measure/splice/measure technique employed previously in laboratory controlled environment or on smaller scale projects. This has proved to have a significant time-saving effect when splicing a number of cable lengths into a single long span.

An innovation still under discussion, is the armored mushroom. Basically, it is a mid-point test location, or an above-surface splice. It had previously been assumed that buried splices would provide, like the cable, more security, but further investigation indicates that above-surface access to the fiber is required for trouble location, maintenance concerns and system restoration. The steel "mushroom" is attached atop a standard telephone stub pole.

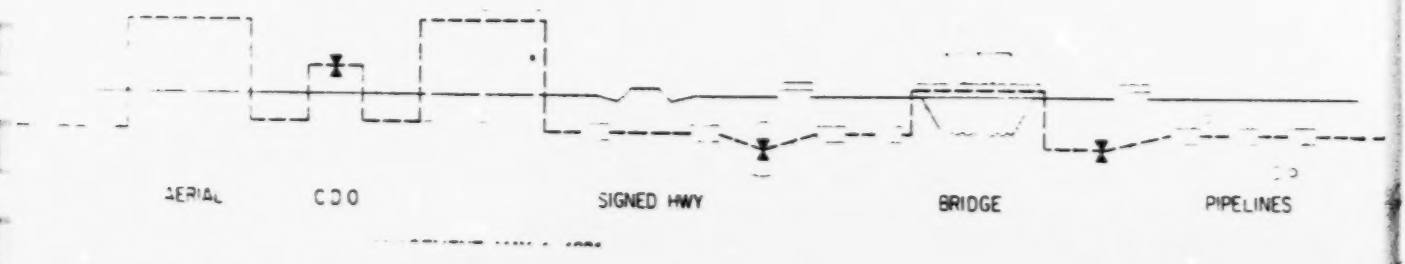
The location of the Northern Telecom facility within the province has proved beneficial to the project. The SASK TEL project team believed that the closer the supplier is, the better the solutions are to the problems that crop up.

Among the innovations that Northern Telecom has had to come up with are large-scale use of gopher protective tape, and to guard against the ingress of water, powder fill. Gopher tape is not new, but application of the corrugated bright steel on the massive scale needed to deal with this particularly nasty pocket gopher, meant that a new highly economical machine and process had to be designed. SASK TEL is rapidly becoming the leading consumer of rodent protective sheathing.

Powder fill for water blocking, a means of protecting cable against water flooding damage is something that had been done before—but in copper applications. Northern is now using it for the SASK TEL job because grease and other filling compounds are too messy and very temperature sensitive—a problem in the portions of the network strung from poles. On a network of this size and complexity, pressurizing would have been both costly and complicated.

Northern Telecom's Optical Systems Division opened its first manufacturing line in Saskatoon this March—only a year after the initial announcement was made. Marketing and administration people had been working there for the previous eight months. The entire 92,000 square foot facility is dedicated to the development, production and marketing of optical systems. The Saskatoon development is part of Northern Telecom's philosophy of expanding where its markets are. Western Canada is currently the part

The first official reel of fiber optic cable was plowed in Saskatchewan, last fall. The cable is buried between five and six feet deep; hopefully this will prevent cut cables.



of the country where there is strong economic growth.

The fiber cable used in SASK TEL's broadband project contains 12 fibers, operating at the digital rate of 44.7 megabits per second. A copper pair has been inserted for use as a talk pair during installation. Local CATV distribution off the "backbone" part of the network is on conventional 35 channel co-ax.

The BBN network will become part of an all-digital integrated system, and projections are that by the year 2000 Saskatchewan will have a primarily digital telephone system, including the switches.

The first 120 miles of the fiber optics system will link Regina, the capital city of the province, and the site of SASK TEL's headquarters, with the city of Yorkton near the Manitoba border. Plowing of the trial section began before freeze-up last year, and will be completed this summer. This initial trial system will be used to determine design modifications that may be required before the rest of the network is installed.

SASK TEL expects to plow an additional 480 miles of cable before the season ends.

The heart of Canada's bread basket is used to the plowing concept, and not only on their farms—they do 8,000 miles of copper cable a year that way. But it was decided that the optical cable needed to be plowed to a deeper level so D-8 equivalent crawler tractors, equipped with plows specially designed for this job, were brought in to bury it at a depth of five to six feet. The hope is that no one else would be plowing that deep, thus preventing the long-time problem of cut cables.

SASK TEL gives credit to Bell Canada and BNR for doing much of the early work in the development of the optical systems that Northern Telecom is now producing and SASK TEL using. This kind of pioneer work cannot be done by a smaller telco like SASK TEL, say the project team. But SASK TEL is quite happy to be pioneering in the large scale application of fiber. After all, the province is still young enough to be quite close to its pioneer roots.

The province is finding other spin-off benefits—besides the recognition of it as a world leader in the application of a new technology.

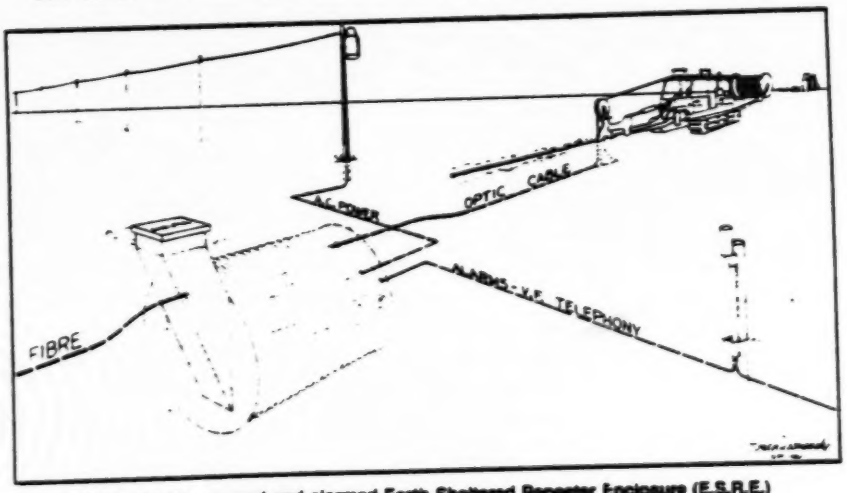
Both the province and the city of Saskatoon are using the location of a large high-technology electronics facility there to attract other high-technology industries. Suppliers of materials necessary for production are also indicating an interest in the province.

A SASK TEL training crew learn the intricacies of making an aerial splice. In this case the cable will be looped back to the test van, where accurate measurements can be made to determine whether the splice is satisfactory.

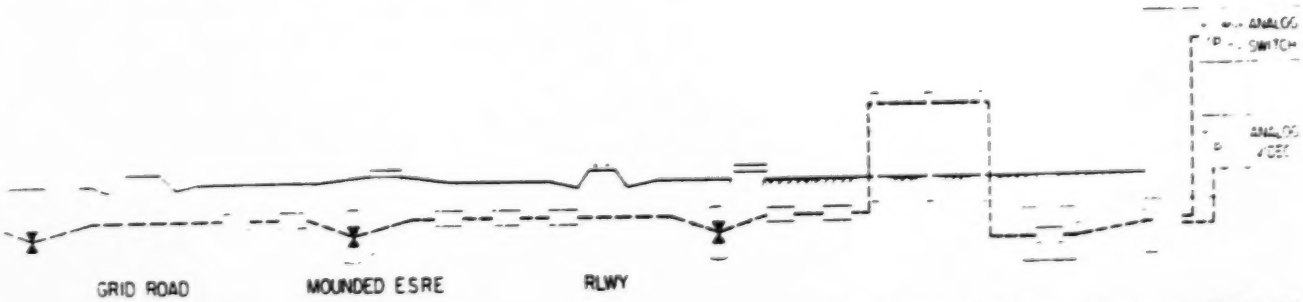
The universities have begun altering their course content to provide specialist courses for graduates who now will be able to stay in the province.

And, of particular interest to the telco, there is an increase in the growth of digital facilities in two ways. One, switched analog growth is being picked up on digital trunks and, two, the conversion from analog to digital switching has been accelerated. Hence the plans for integration of telephony and CATV are developing at a rate faster than expected.

It is all happening in Saskatchewan now. And, already, graduates who had left the province because they felt they had to, to find suitable employment, have heard the word, and have started returning home. ☎



Typical side powered and alarmed Earth Sheltered Repeater Enclosure (E.S.R.E.)



Fiberoptics Plus Multiplexing Wil

In REA's second fiberoptic trial system, plans call for wavelength division multiplexing to be used when capacity is reached in this high growth area.

By Gilbert G. Linnabery, Dr. Marshall C. Hudson, David F. Hemmings and Harry M. Hutson

On Jan. 30, 1981, the Rural Electrification Administration's (REA) second fiberoptic telephone field trial system went into service in Sugar Land, Tex. During installation of the system, REA worked closely with Sugar Land Telephone Co. to apply lightwave communications in the field.

A fiberoptic transmission system was chosen in the Sugar Land trunking application because it offered the most economical way to accommodate rapid circuit growth occurring in the telco's suburban Houston service area. Located 20 miles southwest of downtown Houston, Sugar Land is situated in the center of a 65-square-mile service area that is experiencing a 25% main station growth per year. With the number of homes in the area expected to double from 10,000 to 20,000 by 1984, and an annual commercial growth of 40%, Sugar Land Tel has divided its telephone service area into three exchanges. Projections indicate that the telco's main station base will continue to double approximately every four years until a maximum projected density of 125,000 homes is reached, around the turn of the century.

The fiberoptic trunking system links the First Colony CO with the Sugar Land CO, 3.6 miles away. The First Colony exchange will serve the southeastern quadrant of Sugar Land Telephone's territory; this section is currently expanding most rapidly. Seven new housing developments currently are under construction at First Colony, and total population is expected to peak at 80,000. In addition to First Colony, Sugar Land Tel is planning to put the Clodine exchange, located in the western portion of its service area, into operation by the end of 1981.

Traffic between the First Colony CO and the Sugar Land CO will be heavy because all voice grade toll and Extended Area Service (EAS) calls to and from First Colony are routed through Sugar Land, first. The bulk of the circuits will support Sugar Land Tel's EAS, which is part of one of the nation's largest in calling area size. Sugar Land Telephone customers can call toll free up to 90 miles with access to over 2.4 million phones in Houston. More than 2000 trunk lines link the Sugar Land CO with Houston. Initially, there will be 300 trunks serving the 1400 First Colony customers. Additional trunks will be added as new customer growth demands.

Before fiberoptics was selected as the transmission medium for this new CO connection, Sugar Land Tel and its consultant, Southwestern Engineering, Comfort, Tex., evaluated costs of 1200-pair T-Screen cable, based on a 10-year growth requirement. The capacity of the T3 fiberoptic system proposed, cost-competitive with conventional cable, would not be exhausted until 1995 when Wavelength Division Multiplexing (WDM) couplers may be employed to quadruple the carrying capacity of the fiberoptic cable. The 12-fiber cable, with a capacity of 3360 protected circuits at a transmission of 45 Mb/sec, could carry over 13,000 conversations with WDM techniques.

After finding that fiberoptics was cost-effective for the rapidly growing Sugar Land service area, Sugar Land Tel awarded the system contract to Harris Corp., Melbourne, Fl., supplier of the FT3 lightwave equipment and installation supervisor for the project. Valtec, a Philips-M/A-COM Venture, in West Boylston, Mass., supplied the fiberoptic cable and splice closures. The 5.7 kilometers of 12-fiber cable were installed by the telephone company with the support of Valtec field engineers.

Sugar Land Telephone's fiberoptic system installation took place in September 1980. Valtec supplied the 3.6 miles of fiberoptic cable in seven lengths which were installed in concrete telephone duct and direct-buried PVC conduit.

The cable was a totally dielectric design consisting of 12 individual

Valtec technicians (l) seek shelter from hot Texas sun to perform fusion splicing, closeup at right.

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:retch Sugar Land System's Life

fiber channels stranded around an epoxy-impregnated Kevlar central strength member and covered with an outer jacket of polyethylene. Due to the high water table in the Houston area, manholes stay wet most of the time. The dielectric nature of optical fibers enables cables to be placed in ducts containing water, oil, etc.; this was considered another plus in favor of the fiberoptic technology. To insure the cable's integrity over the projected 30-year lifetime of the system, each fiber is protected in its own gel-filled buffer tube and cable interstices are water-blocked with flooding compound to prevent moisture penetration.

Pulling the cable along the route took four days. A special fiberoptic cable pulling grip designed by the Kellems Division of Harvey Hubbell Inc. (Stonington, Conn.) was used during the installation. The prototype grip featured a built-in rotating pulling eye, thereby eliminating the need for a swivel attachment. Installation crews found that preparation time for cable pulls was shortened.

Crews also found that the lightness of the fiberoptic cable did not diminish its strength. The strength of the Valtec cable and holding power of the Kellems grip were tested when, at one point, pulling tension on the leader line exceeded 800 pounds. The cable suffered no damage when the pull line broke.

Once the cable was in place, splicing began. Valtec field engineers, using the fusion splicing process, completed a total of 72 fiber connections at six field splice points.

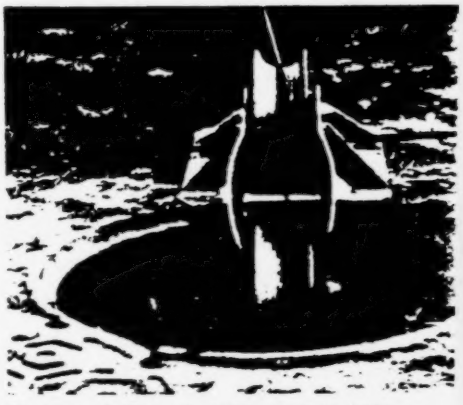
The fusion technique consists of joining individual fibers in adjacent cables by heating the glass to the softening point and permanently fusing them together with an arc current. At either end of the cable route, the cable was terminated with connectors supplied by Harris.

Bandwidth and attenuation measurements on the Sugar Land Telephone installation showed that system specifications were well exceeded. A 90 MHz end-to-end bandwidth at 850nm was required. The actual bandwidth averaged 135 MHz, end-to-end, with a maximum reading of 157 MHz and a minimum of 117 MHz. At the short wavelength (850nm), attenuation was specified at 4.5 dB/Km, which translated into 25.7 dB end-to-end loss, before splicing. Valtec's total span attenuation measurements, including 72 fusion splices, averaged out at 23.5 dB ± 1.3 dB, over the 5.7 kilometer distance. These bandwidth and attenuation measurements will be checked periodically, to meet the 18-month REA field trial requirements.

Harris' FT3 line terminating equipment and M1-3 multiplexers provide the interface between the fiberoptic cable and the conventional T1 lines in each Sugar Land Tel CO. The M1-3 multiplexers are standard products which may be used with other transmission media, e.g., digital microwave, satellite and coaxial cable. The FT3 line terminating equipment products, however, are designed specifically for high-performance fiberoptic systems. Upon installation in October 1980, the bit error rate for the system was approx. 10^{-12}. Harris equipment includes inservice monitoring, orderwire and fault diagnostic functions which improve the maintenance features for the system. The 1 × 1 protection switch is both hitless and error-free; the switch can transfer the T3 signal from one channel to another within a bit period. The bit error rate and the maintenance features also will be checked periodically, to meet the 18-month REA field trial requirements.

In addition to short wavelength transmission, Sugar Land Telephone's cable system is designed for long wavelength transmission when the present capacity is exhausted. Measurements at 1300nm showed an average system loss of 5.7 dB. Taking into account that measurements were made over the entire 5.9 Km of cable shipped, losses at the longer wavelength are less than 1 dB/Km. The present high bandwidth of the cable, combined with future wavelength division multiplexing, will allow Sugar Land Telephone to meet the demands of its rapidly growing service area and heavy EAS requirements. ☎

Sugar Land Tel crew member applies lubricant to cable prior to pull.



Close-up of fiberoptic cable as it is being pulled through duct.

Lightweight fiberoptic cable is fed into manhole during Sugar Land installation.